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FIRST PRINCIPLES

OF

NATURAL PHILOSOPHY.

A TEXT-BOOK

FOR COMMON SCHOOLS.

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BY

ELROY M. AVERY, PH. D.,

AUTHOR OF A SERIES OF TEXT-BOOKS ON PHYSICAL SCIENCE.

SHELDON AND COMPANY,

NEW YORK AND CHICAGO.

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PREFACE

THIS book is the result of an attempt to meet the wants of schools which cannot give the time required for the completion of the author's *Elements of Natural Philosophy*. No effort has been spared by author or publishers to make it worthy of the place it is intended to fill.

Especial care has been taken to provide simple, *teaching experiments* which do not require expensive apparatus.

The latest developments of science, such as the introduction and use of electrical units, have been freely utilized ; the mere polemics of physics has been ignored.

Any teacher or pupil using this book and finding any error therein is requested to communicate the same to the publishers or author.

If, in its study, any person encounters difficulties not easily removable by other means, he may feel free to write to the author (in care of the publishers) for further information. Such letters should be accompanied with addressed envelopes for replies.

CONTENTS

CHAPTER I.

MATTER.

CHAPTER II.

MOTION AND FORCE—DYNAMICS—GRAVITATION —ENERGY.

CHAPTER III.

SIMPLE MACHINES.

CHAPTER IV.

LIQUIDS.

CHAPTER V.

PNEUMATICS.

CHAPTER VI.

ELECTRICITY AND MAGNETISM.

CHAPTER VII.

SOUND.

CHAPTER VIII.

HEAT.

CHAPTER IX.

LIGHT.

CHAPTER I.

MATTER.

SECTION I.

MASSES, MOLECULES AND ATOMS.

"**Read Nature in the language of experiment.**"

Experiment I.—Place a cork on the surface of water. Invert a glass tumbler or jar over the cork and push the glass down into the water. Notice that the water cannot enter far into the vessel, although it enters far enough to show that *its tendency* is thus to enter, but that something prevents it. The air in the glass prevents the water from entering. **Air and water cannot be in the same place at the same time.**

Experiment 2.—Try to get your two hands in the same place at the same time. Repeat the attempt with two books and other articles, until you are sure that **no two things that you can handle can be in the same place at the same time** and that every one of them takes up room.

1. What is Matter?—*Matter is anything that occupies space or "takes up room."*

Mind, truth and hope do not take up room and so we know that they are not forms of matter. The earth, the air, a table, an orange, a slate or a raindrop does take up room and so we know that each is a kind or form of matter.

2. Divisions of Matter.—*Matter exists in atoms, molecules and masses.*

It is very important that we clearly understand what these words mean or we shall have trouble in trying to understand much that is to follow.

3. What is an Atom?—*An atom is the smallest quantity of matter that can enter into combination and thus form molecules and masses.*

In nearly every case an atom is a part of a molecule.

(*a.*) We may say that atoms are the smallest particles of matter that can exist. They seldom exist alone, but quickly unite with others like themselves to form *elementary molecules*, or with others unlike themselves to form *compound molecules.* For example, one atom of oxygen combines with another like itself to form an elementary molecule of oxygen, while one atom of oxygen combines with two of hydrogen to form a compound molecule of water. There are sixty-six kinds of atoms now known.

4. What is a Molecule?—*A molecule is a quantity of matter so small that it cannot be divided without changing its nature.*

The word molecule means "a little mass," but in Natural Philosophy we must be very careful to use the word with accuracy—that is, in accordance with the above definition.

(*a.*) A molecule is so very small that a total of 8,000,000,000 molecules of water is barely visible in the best of modern microscopes. If a drop of water could be magnified until it appeared to be as large as the earth on which we live, each molecule in the drop thus magnified would still look smaller than a base-ball. But while the pupil may thus get the idea that a molecule is very small, he must not think that, like the fairies, it exists only in

fancy. Molecules are as real as base-balls and much more numerous. If a molecule, by any means, be divided, its nature will be changed. A molecule of water may be changed into two atoms of hydrogen and one of oxygen.

(*b.*) In an elementary molecule the atoms are alike; in a compound molecule the atoms are of two or more kinds. Some compound molecules are very complex. The common sugar molecule contains forty-five atoms of three kinds. Elementary molecules make elementary masses or substances. Compound molecules make compound masses or substances. The nature of the molecule determines the nature of the substance.

5. What is a Mass? — *A mass is any quantity of matter that is composed of molecules.*

If a quantity of matter is large enough to be seen, even with a powerful microscope, you may know that it is a mass. If it may be divided without changing the nature of the substance, you may be sure that it is a mass.

Masses are elementary or compound. An elementary mass is called *an element.* There are as many elements as there are kinds of atoms. Compound masses or substances are innumerable.

(*a.*) We may take a lump of salt, which is a mass, and break it into many pieces; each piece will be a mass. We may take one of these pieces and crush it to finest powder; each grain will still be a mass. We may imagine one of these grains of powdered salt to be divided into so many parts that any further division will change them from salt to something else. These particles of salt, which are so small that further division would *change their nature,* are too small to be called masses; they are molecules. If one of these molecules be divided, it will cease to be salt. Instead of salt, we shall have an atom of chlorine gas and an atom of the metal sodium. Two molecules would make a mass, but the mass would be so small as to be invisible, except in imagination.

Experiment 3.—Heat the mercury in the bulb of a common thermometer. The bulb remains full, but the liquid rises in the tube. There seems to be more mercury than there was before. How can this be? There must be a greater number of molecules, the molecules must be larger or **they must be farther apart.**

Experiment 4.—Heat some water in a glass tube without boiling it. Bubbles arise and attach themselves to the sides of the tube. These are bubbles of air. This air came from the water. The air particles were either in the same place with the water molecules, at the same time, or were in otherwise vacant spaces between the water molecules. **Can you believe that they were in the same place at the same time?**

Experiment 5.—Carefully pour alcohol into a test tube about three quarters full of water *until the tube is full.* Close the mouth of the tube with thumb or finger and shake the liquids until they are mixed. Notice that the tube is not full now. Some of the molecules have been destroyed or dropped into the spaces between other molecules. **Can you believe that any of the molecules were destroyed?**

Experiment 6.—Make a common goose quill pop-gun. Notice that when you use it the air confined between the two wads is compressed or made to occupy about half its original space. The air particles were reduced in size or in number, or were crowded together more closely. **Perhaps the matter of which a body is made does not actually fill all the space which the body seems to occupy.**

6. Continuity of Matter.—When you look at a brick wall from a considerable distance, it has an apparent uniformity of structure; you cannot see that it is made of many bricks, separated by mortar-filled spaces. This is the fault of your sense of vision and not the fault of the wall. As you come nearer, you see what

you did not see before—the individual and separated bricks. *But such is the structure of the wall whether you can see it or not.*

Rub the smooth handle of a fine awl over a piece of fine wire gauze and the gauze seems to present a continuous surface. It is the fault of the instrument in your hand and not the fault of the gauze. Rub the point of the awl over the gauze and you soon find openings between the metal threads. *But the openings are there whether you can feel them or not.*

Rub the point of a fine sewing needle over the surface of a window pane. The glass seems to be continuous in its structure and the needle cannot get through. It is the fault of the instrument you are using. Try one more delicate. Let a ray of light fall upon the glass and it easily finds a passage way between the solid molecules. Rays of light are often used by scientific men as instruments for their work.

There are spaces between the molecules of every form of matter, whether you can detect them by any of your physical senses or not.

7. Forms of Attraction.—Each of these three divisions of matter has its form of attraction.

The attraction of masses is called gravitation.

The attraction of molecules is called cohesion or adhesion.

The attraction of atoms is called chemical affinity.

8. Forms of Motion.—It is probable that each of these three divisions of matter has its own form or mode of motion.

The motion of a mass is often called mechanical motion. The motion of a hammer or of a flying bullet is an example.

The motion of the molecules in a mass constitutes heat or light or, probably, electricity or magnetism. If a flying bullet strike the target, we may imagine that the shock which destroys its mechanical motion, produces or increases the vibration of the molecules among themselves. We ought to have little difficulty in imagining these little molecules rapidly swinging to and fro within the mass. These molecular vibrations constitute heat. We know that when a bullet is stopped by the target, the bullet is heated and the production of heat is to be explained only in this way.

The motion of atoms within the molecule is probable, but has not yet been proved.

(*a.*) Fancy a million flies surrounded by an imaginary shell. If each fly be allowed to represent a molecule, the contents of the shell will represent a mass, because it is composed of many molecules. We may imagine this shell to be thrown through the air. The motion of the shell would represent mass or mechanical motion. As the shell is moving through the air, the flies are moving slowly among themselves within the shell. This motion of the flies represents molecular motion and is a very different thing from the motion of the shell. When the shell strikes the ground, the mechanical motion is destroyed but the molecular motion is increased, for the flies are set in much more rapid motion by the shock. This is just about what happens when the bullet is fired against the target.

(*b.*) These motions of atoms, molecules and masses give to matter the power of doing work, the scientific name of which power is *Energy*.

(*c.*) Try to get a clear mental picture of these molecules, *each separated from its neighbor* by a distance much greater than its own diameter. If a mass could be magnified until its molecules were as large as worlds, the spaces between the molecules would be as great as the spaces between the planets. Try to imagine a creature small enough to live on a molecule as we live on the earth. Imagine this creature looking at the neighboring molecules as we look upon the stars at night. Remember that each molecule is in motion back and forth among its neighbors, sometimes striking them, perhaps, and rebounding from them. When we heat the mass, we make each molecule move faster, strike harder blows and *push its neighbors further away, thus producing expansion of the mass.*

9. The Constitution of Matter.—*Every body of matter is made of a vast number of minute particles called molecules, no two of which are in contact. Every molecule is ceaselessly vibrating to and fro among its neighbors, often hitting them and rebounding from them.*

10. Physical Science. — *Physical science comprises Physics and Chemistry.*

Physics deals with masses and molecules; chemistry, with atoms and combinations of atoms.

Experiment 7.—Bring a piece of warm sealing wax near some small bits of paper, but without touching them. Notice that the paper bits do not move. Briskly rub the sealing wax with a piece of warm flannel and quickly bring it near the paper bits as before. Notice that the sealing wax *now* produces very peculiar motions in

the paper bits. Notice also that you have wrought an important change in the sealing wax, but that **still the stick is sealing wax.**

Experiment 8.—Rub a brass button on the floor or carpet until it is uncomfortably warm. Notice that while you have produced a change in the button, it is still brass; **you did not change the substance of which it is made.**

11. What is a Physical Change?—*A physical change is one that does not change the nature of the molecule.*

(*a.*) A piece of marble may be ground to powder, but each grain is marble still. Ice may change to water and water to steam, yet the identity of the substance is unchanged. A piece of glass may be electrified and a piece of iron magnetized, but they still remain glass and iron. These changes alter the *distances and arrangement* of the molecules, but leave the molecules themselves unchanged; they are physical changes. A change like the rusting of iron or the burning of wood, changes the nature of the molecule itself, and, consequently, of the substance. *Such a change as this is called a chemical change.*

12. What is a Property of Matter?—*Any quality of matter is called a property of matter.*

Lead is heavy; heaviness is a property of lead. It may be manifested without changing the lead to anything else, and is, therefore, called a *physical property.* Sulphur or brimstone is brittle. The brimstone may exhibit this property and still remain brimstone. Hence, brittleness is a physical property of brimstone.

Sulphur is also combustible—it may be burned. But this property of sulphur (combustibility) can not be shown without changing the sulphur to something else. Such are called *chemical properties of matter.*

13. Definition.—*Physics, or Natural Philosophy, is the branch of science that treats of the laws and physical properties of matter, and of those phenomena that depend upon physical changes.*

14. Recapitulation.—To be reproduced and amplified by the pupil for review.

- PHYSICS. } PHYSICAL SCIENCE.
- CHEMISTRY. }
  - MATTER.
    - Divisions. | Attractions. | Motions.
    - MASSES. — GRAVITATION. — *Mechanical Power.*
    - MOLECULES. — COHESION. ADHESION. — *Heat. Light. Electricity Magnetism.*
    - ATOMS..... — CHEMICAL AFFINITY. — (?)
  - ENERGY.
- CHANGES. { PHYSICAL. CHEMICAL. } PROPERTIES.

SECTION II.

THE PHYSICAL PROPERTIES OF MATTER.

15. **Division of Physical Properties.**—The physical properties of matter are divided into two classes, *universal* and *characteristic*.

16. **What are Universal Properties?** — *Universal properties of matter are such as belong to matter of every kind.*

17. **List of Universal Properties.** — The principal universal properties of matter are *extension, impenetrability, weight, indestructibility, inertia, divisibility, porosity, compressibility, expansibility and elasticity.*

18. **What is Extension?**—*Extension is that property of matter by virtue of which it takes up room.*

It is involved in the definition of matter given in § 1.

(*a.*) In this country and in England, the foot and yard are units commonly used *at the present time.* But in most other civilized countries of the world, the international or metric units are used. These units are almost universally adopted by scientific men even in England and America.

In this book, frequent use will be made of the terms **meter, liter** and **gram**, their multiples and divisions. The pupil should

familiarize himself with these units. He will find further information concerning them in Appendix B. at the end of this volume.

Experiment 9.—Pass a bent tube and a funnel, as shown in Fig. 1, or a funnel tube as shown in Fig. 2, through the cork of a bottle. *Be sure that all joints are air tight.* The delivery tube is best made of glass which may be bent when heated to redness in an alcohol or gas flame. Place the end of the delivery tube in a tumbler of water. Pour water through the funnel. As it runs into the bottle, **air will be forced out** and may be seen bubbling through the water in the tumbler. A bottle convenient for this and other experiments may be prepared by perforating the cover of a glass fruit jar, as shown in Fig. 2. The holes carry cork or caoutchouc stoppers, through which the tubes pass. Full directions for bending glass tubing, boring holes, etc., may be found in Appendix 4, of *Chemistry.*

Fig. 1.

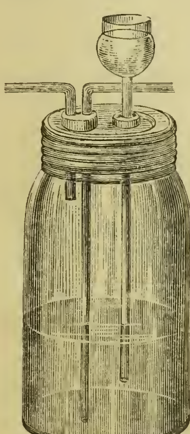

Fig. 2.

Experiment 10.—Thrust a lamp chimney into water. The water will rise inside the chimney, entering at the lower end and pushing the air out at the top. Repeat the experiment, closing the upper end of the chimney with the hand (or use an inverted tumbler). **The water can not rise as before** because the vessel is filled with air that can not escape.

Experiment 11.—Drive a nail into a piece of wood; the particles of wood are either crowded more closely together to give room for the nail, or some of them are driven

out before it. **Clearly, the iron and the wood are not in the same place at the same time.**

19. What is Impenetrability? — *Impenetrability is that property of matter by virtue of which two bodies can not be in the same place at the same time.*

20. What is Weight?—*Weight is the measure of mass attraction or gravity.*

(*a.*) The word gravity generally points out the tendency of bodies, not supported, *to fall to the ground.*

(*b.*) A body is heavy or light according to the amount of attraction; the greater the attraction, the greater the weight.

(*c.*) If an apple be held in the hand, the attraction between the earth and the apple produces pressure upon the hand. This pressure is not the attraction, but it is the measure of it and is called weight.

(*d.*) If the same apple were upon the moon, its weight would be the measure of the attraction between the apple and the moon. But as the moon has less matter than the earth, the attraction between the apple and the moon would be less than that between the apple and the earth and the weight would, consequently, be less.

21. What is Indestructibility? — *Indestructibility is that property of matter by virtue of which it can not be destroyed.*

(*a.*) No human being can create or destroy a single atom of matter. Water evaporates and disappears only to be gathered in clouds and condense and fall as rain. Wood burns, but the ashes and smoke and the invisible gases formed, contain the identical

atoms of which the wood was composed. In a different form, the matter still exists and weighs as much as before it was burned. The experiment is difficult, but has been repeatedly performed. The universe contains the same atoms to-day that it did at the close of the creation—not one more, not one less.

Experiment 12.—Upon the tip of the fore-finger of the left hand, place a common calling-card. Upon this card and directly over the finger, place a cent. With the nail of the middle finger of the right hand, let a sudden blow or "snap" be given to the card. A few trials will enable you to perform the experiment so as to drive the card away and leave the coin resting upon the finger. The card flies away on account of the force of the "snap." The cent remains on the finger because the blow is so quick that **the card has no time to give any of its motion to the coin.**

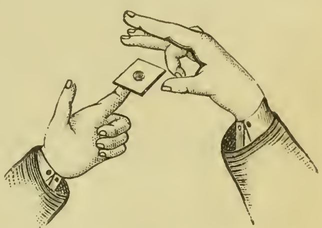

FIG. 3.

Experiment 13.—To make the experiment still more interesting, use a bullet instead of the cent and the open top of a bottle instead of the finger-tip. Keep trying until you succeed in dropping the bullet into the bottle. The experiment illustrates the inertia of the bullet, the card being driven away before it has opportunity to impart its motion to the bullet.

22. What is Inertia?—*Inertia is that property of matter by virtue of which it has a tendency when at rest to remain at rest or when in motion to continue in motion.*

(*a.*) A ball cannot put itself in motion. When the ball is thrown through the air, it has no power to stop and it will not stop until some external force compels it to do so. This external force may

be the bat, the catcher, the resistance of the air or the force of gravity. It must be something *outside the ball* or the ball will move on forever.

(*b*.) Illustrations of the inertia of matter are so numerous that there should be no difficulty in getting a clear idea of this property. The "running jump" and "dodging" of the playground, the frequent falls which result from jumping from cars in motion, the backward motion of the passengers when a car is suddenly started and their forward motion when a car is suddenly stopped, the difficulty in starting a wagon and the comparative ease of keeping it in motion, *etc.*, *etc.*, may be used to illustrate this property of matter.

Experiment 14.—Strike a piece of loaf sugar or of brick with a hammer. **The sugar or brick is separated into many parts.**

23. What is Divisibility? —*Divisibility is that property of matter by virtue of which a body may be separated or divided into parts.*

(*a*.) The divisibility of matter may be carried to such an extent as to excite our wonder and test the powers of imagination itself. It is said that the spider's web is made of threads so fine that enough of this thread to go around the earth would weigh but half a pound and that each thread is composed of six thousand filaments. A single inch of this thread with all its filaments may be cut into thousands of distinct pieces and each piece of each filament be yet a mass of matter composed of molecules and atoms. We may consider that the atom marks the limit of divisibility.

Experiment 15.—Fill a test tube with water. Slowly add sugar. A considerable quantity may be added without increasing the bulk of the liquid.

Experiment 16.—Take a test tube three quarters full of water and carefully add alcohol until it is filled. Close the tube with the thumb and shake. Notice that the tube *is no longer* full. We know that the water and the alcohol cannot be in the same place

at the same time and are forced to the conclusion that **some of the water molecules have been received into the space between the alcohol molecules or** ***vice versa.***

24. What is Porosity?—*Porosity is that property of matter by virtue of which spaces exist between the molecules.*

(*a.*) When iron is heated, the molecules are pushed further apart, the pores are enlarged and we say that the iron has expanded. If a piece of iron or lead be hammered, it will be made smaller because the molecules are forced nearer together, thus reducing the size of the pores.

(*b.*) These pores are very large in comparison with the size of the molecules. As was said a few pages back, if a race of persons could be imagined small enough to live on a molecule as we live on our earth, we might fancy them looking across the space around it and seeing the nearest molecule as we look off into the sky and see the moon or stars.

(*c.*) Cavities or cells, like those of bread and sponge, are sometimes improperly spoken of as pores.

25. What is Compressibility?—*Compressibility is that property of matter by virtue of which a body may be reduced in size.*

Experiment 17. — Invert a thin glass bottle over a plate of water, as shown in Fig. 4. The heat of the hand will expand the air in the bottle and some of it will escape in bubbles. If no bubbles appear, pour warm water over the bottle.

FIG. 4.

26. What is Expansibility? — *Expansibility is that property of matter by virtue of which a body may be increased in size.*

(*a.*) Compressibility and expansibility are the opposites of each other, resulting alike from porosity. Let each pupil prove, by experiment with an ordinary pop-gun or other apparatus, that air is compressible and expansible.

Experiment 18.—Provide strips of rubber, whalebone, wood, iron, steel, brass, copper, zinc and lead. Stretch the piece of rubber and notice what takes place when the stretching force ceases to act. Bend each of the other strips and notice what takes place under similar circumstances.

27. What is Elasticity? — *Elasticity is that property of matter by virtue of which bodies resume their original form or size when that form or size has been changed by any external force.*

All bodies possess this property in some degree. Solid bodies have elasticity of form; liquids and gases have not.

(*a.*) Different substances possess this property in different degrees.

Solid bodies are not perfectly elastic. They may contract after being stretched or expand after being compressed but **they do not return to exactly their former size.**

Liquids and gases are perfectly elastic. No matter how great the pressure that may be exerted upon them, **they return to exactly their former size** when the pressure is removed.

The ordinary spring-balance owes its value to the elasticity of the spiral steel spring, which is stretched by the weight.

28. What are Characteristic Properties? — *Characteristic properties of matter are such as belong to matter of certain kinds only.*

They enable us to distinguish one substance from another. Glass is brittle, and by this single property may be distinguished from India-rubber.

29. List of Characteristic Properties. — The characteristic properties of matter are numerous. They depend chiefly upon cohesion and adhesion. The most important are *hardness, tenacity, brittleness, malleability and ductility.*

Experiment 19.—Take a sheet of gold-leaf in your fingers and try to pick the metal off with the fingers of the other hand. Some of the gold will "stick to your fingers."

30. What are Cohesion and Adhesion? — *Cohesion is the force that holds together like molecules; adhesion is the force that holds together unlike molecules.*

(*a.*) Cohesion is the form of molecular attraction that holds most substances together and gives them form. If you pull on an iron wire and are unable to break it, you are to understand that the cohesion of the iron particles is stronger than you are.

(*b.*) Adhesion is the form of molecular attraction that causes the pencil or crayon to leave marks upon the paper or blackboard and makes paste, glue, mortar and cements "stick."

(*c.*) In a brick wall, cohesion binds together the molecules of the mortar layer into a single, hardening mass; adhesion reaches out and grasps the adjoining bricks and holds them fast—a solid wall. Each acts only through distances too small to be measured.

Experiment 20.—Get pieces of chalk, glass, iron, lead, copper and marble. Try to scratch each one with each of the others. Make a note of the result of each experiment, thus :

Glass will scratch copper ; copper will not scratch glass. Determine which is the hardest substance in your collection and which is the softest.

31. What is Hardness?—*Hardness is that property of matter by virtue of which some substances resist any attempt to force a passage between their particles.*

It is measured by the degree of difficulty with which one substance is scratched by another. Fluids are not said to have hardness.

32. What is Tenacity?—*Tenacity is that property of matter by virtue of which some substances resist a force tending to pull their particles asunder.*

(*a.*) Like hardness and the other characteristic properties of matter, it is a variety of cohesion which is the general term for the force which holds the molecules together and keeps masses from crumbling into dust.

33. What is Brittleness?—*Brittleness is that property of matter by virtue of which some substances may be easily broken, as by a blow.*

(*a.*) Glass furnishes a familiar example of this property. The idea that brittleness is the opposite of hardness, elasticity or tenacity, should be guarded against. Glass is harder than wood, but very brittle; it is very elastic, but very brittle also. Steel is far more tenacious than lead and far more brittle.

34. What is Malleability? — *Malleability is that property of matter by virtue of which some substances may be rolled or hammered into sheets.*

(*a.*) Gold is the most malleable metal. It has been beaten so thin that a pile of 282,000 leaves would be but an inch high.

Experiment 21.—Heat the middle of a piece of glass tubing about six inches long, in an alcohol flame, until red-hot. Roll the ends of the glass slowly between the fingers and, when the heated part is soft, quickly draw the ends asunder. That the fine glass wire thus produced is still a tube, may be shown by blowing through it into a glass of water and noticing the bubbles that will rise to the surface.

35. What is Ductility?—*Ductility is that property of matter by virtue of which some substances may be drawn into wire.*

(*a.*) Platinum wire has been made $\frac{1}{30000}$ of an inch in diameter. Glass, when heated to redness, is very ductile, as was shown in the last experiment. All ductile substances are tenacious, but a tenacious substance is not necessarily ductile.

36. Recapitulation.—To be reproduced and amplified by the pupil from memory.

PHYSICAL PROPERTIES OF MATTER.
- GENERAL. .... *Extension, Impenetrability, Weight, Indestructibility, Inertia, Divisibility, Porosity, Compressibility, Expansibility, Elasticity.*
- CHARACTERISTIC.
  - ADHESION.
  - COHESION.
    - *Hardness.*
    - *Tenacity.*
    - *Brittleness.*
    - *Malleability.*
    - *Ductility.*

SECTION III.

THE THREE CONDITIONS OF MATTER.

37. Conditions of Matter. — *Matter exists in three conditions or forms—the solid, the liquid, and the aeriform.*

Ice is solid; water is liquid; steam is aëriform.

38. What is a Solid?—*A solid is a body whose molecules move among themselves with difficulty.*

Such bodies have a strong tendency to retain any form that may be given to them. A movement of one part of such a body produces motion in all of its parts.

Experiment 22.—Place your finger in a vessel of water and move it about. The watery particles easily flow over and around one another; there is great freedom of molecular motion. Remove your finger, holding the tip downward. The water molecules instantly glide into the space lately occupied by your finger, which leaves no hole behind it. Notice that a drop of water hangs upon your finger tip. That drop contains many molecules which cling together, held by the force of cohesion, while the drop clings to your finger, held by the force of adhesion.

Experiment 23.—Suspend a glass or metal plate, of about four inches area, from one end of a scale-beam and accurately balance the same with weights in the opposite scale-pan. The supporting cords may be fastened to the plate with wax. Beneath the plate, place a saucer so that when the saucer is filled with water

the plate may rest upon the liquid surface, the scale-beam remaining horizontal. Carefully add small weights to those in the scale-pan. Notice that the water *beneath the plate* is raised above its level. Add more weights until the plate is lifted from the water. Notice that the under surface of the plate is wet. These water molecules on the plate have been torn from their companions in the saucer. The added weights were needed to overcome **the tendency of the water molecules to cling together.**

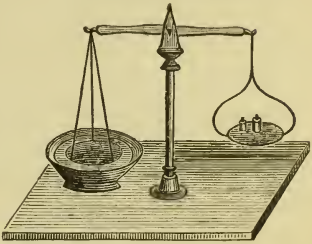

FIG. 5.

NOTE.—After seeing a physical experiment, always ask yourself, "What was the object of that experiment? What does it teach?" Never allow yourself to look upon an experiment as being simply entertaining; thus reducing the experimenter, *so far as you are concerned*, to the level of a showman.

39. What is a Liquid?—*A liquid is a body whose molecules easily move among themselves, yet tend to cling together.*

Liquids adapt themselves to the form of the vessel containing them but do not retain that form when the restraining force is removed. They always so adapt themselves as to have their free surfaces horizontal. Water is the best type of liquids.

40. What is an Aëriform Body?—*An aëriform body is like air. Its molecules easily move among themselves and tend to separate from each other almost indefinitely.*

A vessel may be half full of a solid or a liquid but not of an aëriform substance. Atmospheric air is the best type of aëriform bodies. Aëriform means "having the form of air."

Experiment 24.—Place a piece of ice in a large metal spoon. Hold the bowl of the spoon in the flame of a lamp. Notice that the solid ice changes to liquid water and finally disappears as a vapor.

Experiment 25.—Heat half a brick in the stove, place it on any convenient support, drop a few scales of iodine (which you can get at the chemist's) upon the brick and cover the brick with a large bell glass. The glass will quickly be filled with the beautiful violet colored vapor of iodine. Notice whether the iodine changes to a liquid before it becomes a vapor, as the ice did.

41. Gases and Vapors.—Aëriform bodies are of two kinds, gases and vapors.

Gases remain aëriform under ordinary conditions, although they may be changed to the liquid form by intense cold and pressure. Oxygen is a gas.

Vapors are produced by heat from substances that are generally solid or liquid. They resume the solid or liquid form at ordinary temperatures. Steam is a vapor.

42. Changes of Condition.—The same substance may exist in two or even three of these forms. Most solids, as lead and iron, may be changed by heat to liquids; others, as iodine, may be apparently changed directly to vapors; still others, as ice, may be easily changed first to the liquid and then to the vapor form. It is probable that our present inability to liquefy and vaporize certain substances arises from our limited means

for the production of heat. Many substances that formerly could not be melted are easily melted in the arc of the now common electric lamp. With this idea in mind, we may say that a solid is frozen matter; that a liquid is melted matter; that a gas is vaporized matter.

43. Ultra-Gaseous Form of Matter. — Recent experiments with electric discharges in high vacuums [§§ 187, 239, 306,] have yielded remarkable results which, in the opinion of many, prove the existence of a fourth condition of matter. For matter in this extremely thin or attenuated form, the name "Radiant Matter" has been proposed.

(*a.*) In a very remarkable lecture on this subject (August 22, 1879), Prof. Cookes said :—

"Gases are considered to be composed of an almost infinite number of molecules, which are constantly moving in every direction with velocities of all conceivable magnitudes. As these molecules are exceedingly numerous, it follows that a molecule can not move far in any direction without coming into contact with some other molecule. But if we exhaust the gas contained in a closed vessel, the number of molecules becomes diminished and the distance through which any one of them can move without coming into contact with another is increased. The mean free path is inversely proportional to the number of molecules present. The further the exhaustion is carried, the longer becomes the average distance a molecule can travel before entering into collision. By thus lengthening the mean free path of the remaining molecules, we obtain phenomena so distinct from anything which occurs in air or gas at the ordinary tension that we are led to assume that we are here brought face to face with matter in a fourth state or condition, one as far removed from the state of a gas as a gas is from a liquid."

44. What is a Fluid?—*A fluid is a body whose molecules easily change their relative positions.*

The term includes liquids, gases and vapors.

45. Recapitulation.—To be reproduced, upon paper or the blackboard, by each pupil.

MATTER.

- **SOLIDS.** Molecules change their relative positions with difficulty
- **FLUIDS.** Molecules change their relative positions easily.
    - **LIQUIDS.** Molecules cling together feebly.
    - **AËRIFORM BODIES.** Molecules tend to separate.
        - GASES; *ordinarily aëriform.*
        - VAPORS; *ordinarily liquid or solid.*

QUESTIONS FOR REVIEW.

1. How should the "Book of Nature" be read?

2. (*a.*) What term is applied to anything that you can see, feel, touch or taste? (*b.*) What is energy?

3. What limits the number of elements?

4. A stone that measures eight cubic inches is quietly placed in a bowl *full* of water. How much water will run out? Why?

5. What is an element?

6. Given a lamp chimney, a small cork and a pail of water; how will you illustrate the compressibility of air?

7. (*a.*) What is the smallest possible division of an element? (*b.*) Of a compound substance?

8. Two hydrogen atoms make a hydrogen molecule. Is hydrogen an elementary or a compound substance?

9. Two hydrogen atoms and one oxygen atom make a water molecule. Is water an elementary or a compound substance?

10. (*a.*) If you thrust a knitting needle into a mass of dough, is the hole thus made a pore? (*b.*) What is a pore?

11. Are the molecules of water larger or smaller than those of steam?

12. Name two classes of fluids?

13. Give an illustration of molecular motion in a mass that is at rest.

14. Which are the greater, the diameters of molecules or the distances between molecules?

15. Are intermolecular spaces greater in water or in steam?

16. What is molecular attraction called?

17. Give an illustration (not contained in this book) of one of the universal properties of matter.

18. What is the difference between a fluid and a liquid?

19. One sixteen thousandth of a cubic inch of indigo dissolved in fuming sulphuric acid will give a perceptible color to two or three gallons of water. What property of matter may thus be illustrated?

CHAPTER II.

MOTION AND FORCE.—DYNAMICS.—GRAVITATION, ETC.—ENERGY.

SECTION I.

MOTION AND FORCE.

46. What is Motion?—*Motion is a changing of position.*

No body can move or be moved from one place to another without motion.

47. What is Force?—As generally used, *force signifies any cause that tends to produce, change, or destroy motion.* All physical phenomena are caused by the action of forces upon matter.

(*a.*) There are many kinds of force. We often hear and speak of the force of muscular action, the force of the wind, the force of gravity, *etc.* We shall soon see that heat, light, magnetism, electricity, *etc.*, may exercise force.

48. What is Dynamics?—*Dynamics is that branch of Natural Philosophy or Physics which treats of forces and their effects.*

(*a.*) The word "mechanics" was formerly used in the sense that we now use the word "dynamics." Mechanics properly denotes the science of machines and is a branch of dynamics.

Experiment 26.—Place on the floor a croquet ball and a heavy iron ball. Strike them equal blows with a mallet. Notice that **equal forces do not always produce equal velocities.**

Experiment 27.—Roll the iron ball and the croquet ball with equal velocities. Find out which requires the greater force to stop its motion.

49. Momentum.—*The momentum of a body is its quantity of motion.*

(*a.*) Momentum depends upon the weight of the moving body and its velocity or rapidity of motion.

Examples.—An iceberg moves very slowly but almost irresistibly, or with great momentum, because *it is very heavy.* A bullet is not very heavy but, when fired from a rifle, it has a great momentum because *it moves with great velocity.*

(*b.*) Momentum is generally measured by the product of the numbers representing the weight and the velocity. The unit of momentum has no definite name.

$$M = W \times V.$$

Examples.—The momentum of a body having a weight of 20 pounds and a velocity of 15 feet, is twice as great as that of a body having a weight of 5 pounds and a velocity of 30 feet. The momentum of the former is 300; that of the latter, 150.

(*c.*) In comparing momenta, the pupil must be careful that the units of weight used are alike. The units of velocity also must be alike. If the weight of one body be given in ounces and that of the other in pounds, they must be reduced to the same denominations. If the velocity of one body be given in feet *per* minute and that of the other in miles *per* hour, a similar reduction must be made.

50. Laws of Motion.—The following propositions, known as Newton's Laws of Motion, are so important and so famous that they ought to be remembered by every pupil.

(1.) *Every body continues in its state of rest or of uniform motion in a straight line unless compelled to change that state by an external force.*

(2.) *Every motion or change of motion is in the direction of the force impressed and is proportionate to it.*

(3.) *Action and reaction are equal and opposite in direction.*

51. The First Law.—This is called the law of inertia, because it results directly from inertia (§ 22). It is impossible to furnish perfect examples of this law, because all things within our reach or observation are acted upon by some external force. A base-ball when once set in motion has no power to stop itself. If its motion was not interfered with, it would move in a straight line but the force of gravity is ever active, turns it from that line and compels it to move in a graceful curve instead.

Experiment 28.—Rapidly whirl a pail, partly filled with water, in a vertical circle. Not a drop will fall from the bucket even when it is upside down because **the water seeks to move in a straight line and thus to move away from the center about which it is swung.**

52. Centrifugal Force.—Although it is impossible to give any experimental proof of the first law of motion, we see many illustrations of the *tendency* of moving bodies to move in straight lines even when forced to move in curves. Examples, such as water flying from a

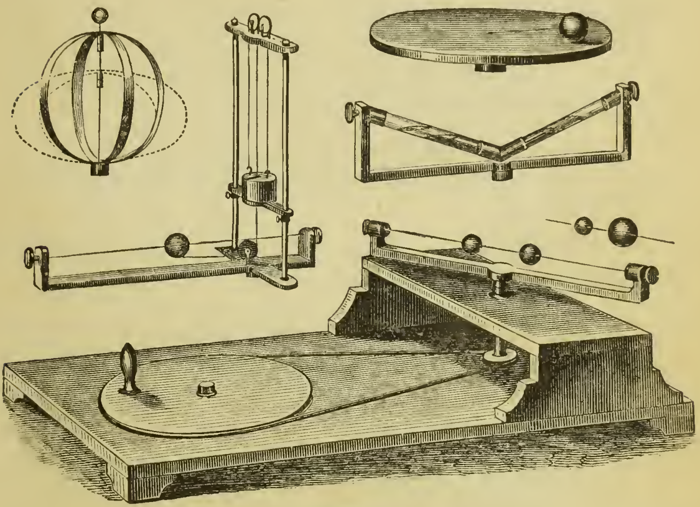

Fig. 6.

revolving grindstone or mud from a carriage-wheel, are familiar to all. A wagon in rapidly turning a corner is likely to be overturned for the same reason. This fact explains why the outer rail on a railway curve is laid higher than the inner one. A stone is thus shot from a sling.

The school-boy is sent rolling in the game of "crack-the-whip" because, while *the mental part* of the boy may

seek to move in a curve in obedience to the pull of his leader, *the material part* of the boy seeks to move in a straight line in obedience to Newton's *First Law of Motion.* The fun of the game arises from the fact that the matter often triumphs over the mind.

This tendency of matter to move in a straight line and, consequently, further away from the center around which it is revolving, is called Centrifugal Force.

(*a.*) The laws of centrifugal force may be studied or illustrated by the whirling table and accompanying apparatus, represented in Fig. 6.

53. **The Second Law.**—The second law of motion is sometimes given as follows:

A given force will produce the same effect whether the body on which it acts is in motion or at rest; whether it is acted on by that force alone or by others at the same time.

(*a.*) If a ball that is moving with a velocity of 50 feet a second be hit with a force that, acting alone, would produce a velocity of 25 feet a second, the ball will have a velocity of 75 feet a second.

(*b.*) If a boat be pulled northward with a force that would give it a velocity of 3 miles *per* hour and, at the same time, pulled eastward with a force that would give it a velocity of 4 miles *per* hour, it will move nearly northeastward and with a velocity of 5 miles *per* hour.

At the end of the hour, the boat will be at the place where it would be if the first force had really moved it 3 miles northward and the second force had then moved it 4 miles eastward.

Experiment 29.—Float upon water two blocks of wood, one of which is twice as heavy as the other. Connect them by a stretched rubber cord. Release the blocks and they will move toward each other, but with unequal velocities. Determine how much faster one moves than the other, and compare their momenta.

54. The Third Law.—Examples of the third law of motion are very common. When we strike an egg upon a table, the action of the egg may make a dent in the table, while the reaction of the table breaks the egg.

The oarsman urges the water backward with the same force that he urges his boat forward.

In springing from a boat to the shore, muscular action tends to drive the boat adrift; the reaction, to put the passenger ashore.

Experiment 30.—Hang two clay balls of equal weight by strings of equal lengths so that they will just touch each other. If one be drawn aside and let fall against the other, **both will move forward, but only half as far** as the first would have moved had it met no resistance.

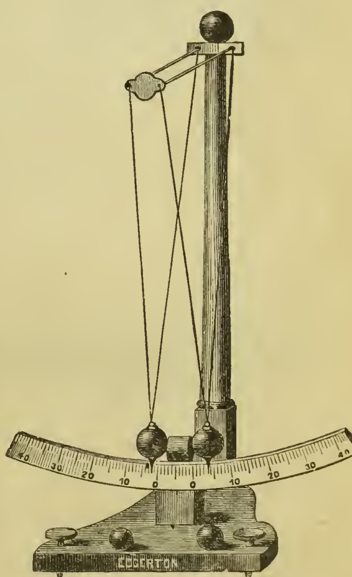

Fig. 7.

Experiment 31.—Place two ivory balls, which are elastic, as you did the clay balls of Experiment 30. Repeat the experiment. **The first ball will give the whole of its motion to the second** and remain still after striking, while the second will swing about as far as the first would have done if it had met no resistance. In this case, as in the former, it will be seen that **the first ball loses as much momentum as the second gains.**

Experiment 32.—Make a railway of two wooden strips, $1\frac{1}{2}$ inches by $\frac{1}{4}$ inch and about six feet long, fastened together by three or five cross-pieces, as shown in Fig. 8. The distance between the rails should be about an inch. Place the railway on a board and fasten down the middle cross-piece with a screw. Spring up the ends and support them by books or wooden blocks. At the toy shop, get several large glass "marbles" and place them on the middle of the railway. Bring one ball to the highest point of the track and let it roll down against the others. Ball No. 1 gives up its motion to No. 2 and comes to rest ; No. 2 gives it to No. 3 and, in turn, comes to rest. The energy is thus passed through the line to No. 7, which is driven some distance on

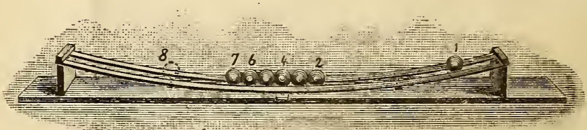

Fig. 8.

the up grade, as to the position shown by the dotted line at 8. From 8, this ball rolls down grade and passes its energy along the line, forcing No. 1 up the grade to a lesser distance than before. The balls will repeat their motions several times until they are finally brought to rest by friction, *etc.*

Experiment 33.—This action of ivory or glass balls is due to the fact that they are elastic, and are flattened by the blow. To show that this is so, smear a flat stone or iron plate with paint. Before the paint becomes dry, place one of the glass balls on the smeared surface and notice the size of the round spot thus made. Then drop the ball from a height of several inches and notice that the spot made is *larger than before.* This shows that the glass ball was flattened just as truly as if it were made of rubber. Elasticity at once restores the original shape.

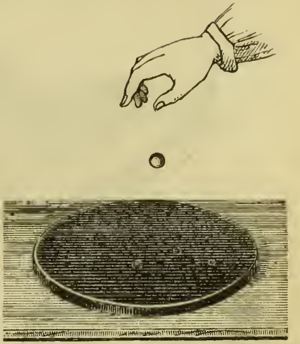

FIG. 9.

55. Effect of Elasticity upon Reaction.—The effects of action and reaction are largely modified by elasticity, but never so as to destroy their equality.

56. Reflected Motion.—*Reflected motion is the motion produced by the reaction of a surface when struck by a body, the surface, or the body, or both being elastic.*

A ball rebounding from the wall of a house is an example of reflected motion.

57. Law of Reflected Motion.—The angle included between the line in which the body moves before it strikes the reflecting surface and a perpendicular to that surface drawn from the point of contact, is called *the angle of incidence.* The angle between the line

in which the body moves after striking and the perpendicular, is called *the angle of reflection.*

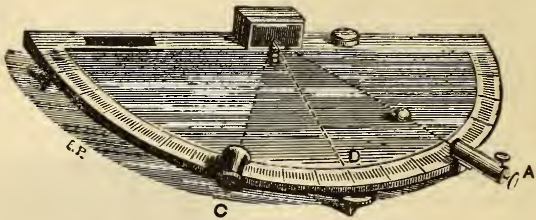

FIG. 10.

The angle of incidence is equal to the angle of reflection.

A ball shot from A will be reflected at B back to C, making the angle of incidence $A\,B\,D$, equal to the angle of reflection, $C\,B\,D$.

58. Recapitulation.—To be amplified by the pupil for review.

- DYNAMICS.
  - FORCE.
    - DEFINITION.
    - FORMS.
    - "CENTRIFUGAL."
  - MOTION.
    - MOMENTUM.
    - NEWTON'S LAWS.
    - REFLECTED MOTION.

EXERCISES.

1. What is the momentum of a 100-pound ball moving 275 feet a second? *Ans.* 27500.

2. A 25-pound ball is moving 100 feet a second. A two-pound bird is flying at the rate of 50 feet a second. The momentum of the ball is how many times as great as that of the bird?

Ans. 25 times.

3. A 50-pound body has a momentum of 1000. What number will represent its velocity? *Ans.* 20.

4. Which has the greater momentum, a steamboat at rest or a canoe in motion? Why?

5. A boat that is moving at the rate of 5 miles an hour weighs 4 tons; another that is moving at the rate of 10 miles an hour weighs 2 tons. How do their momenta compare?

6. A stone weighing 12 ounces is thrown with a velocity of 22 feet a second. An ounce ball is shot with a velocity of 15 miles a minute. Which will have the greater momentum? How many times as great? *Ans.* 5.

7. Can an angle of incidence be greater than a right angle?

8. (*a.*) When water is heated it becomes steam. Is this a physical or a chemical change? (*b.*) When steam is intensely heated it is changed into a mixture of two gases, oxygen and hydrogen. This mixed gas will not condense to water, but will burn and even explode. What kind of a change is this? (*c.*) What was divided in the latter case that was not in the former?

9. Bend a twig and tell what change is thus wrought upon the molecules on the convex side of the twig and what upon those on the concave side.

10. (*a.*) Why are pile drivers made very heavy? (*b.*) Why are they raised to considerable heights?

11. A man weighing 100 pounds stands in a boat that weighs 1000 pounds and pulls on a rope held by a man weighing 200 pounds and standing in a boat weighing 2000 pounds. Compare the velocities and momenta of the two boats.

SECTION II.

GRAVITATION.

59. What is Gravitation?—*Every particle of matter in the universe has an attraction for every other particle. This attractive force is called gravitation.*

60. Laws of Gravitation.—(1.) *Gravitation varies directly as the mass or quantity of matter.*

For example, doubling the mass doubles the attraction; trebling the mass will multiply the attraction by three.

(2.) *Gravitation varies inversely as the square of the distance between the centres of gravity* (§ 65).

For example, doubling the distance quarters the attraction; trebling the distance will divide the attraction by nine.

Doubling both the mass and the distance, will halve the attraction; trebling both the mass and distance will divide the attraction by three $\left(\frac{3}{3^2} = \frac{1}{3}\right)$.

61. What is Gravity?—*Gravity is the attraction between the earth and bodies upon or near its surface.*

It is the kind of gravitation with which we are most familiar. It acts in a vertical direction, as shown by the plumb line, Fig. 11.

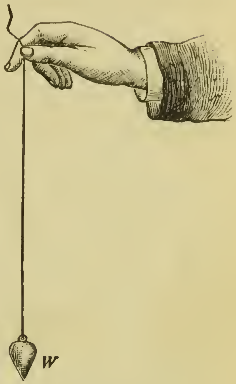

Fig. 11.

62. What is Weight?—*Weight is the measure of gravity.*

The attraction between two pounds of iron and the earth is twice as great as the attraction between one pound of iron and the earth. Because its gravity is twice as great, we say that its weight is twice as great or that it is twice as heavy.

63. Law of Weight.—*Bodies weigh most at the surface of the earth.*

Below the surface, the weight decreases as the distance to the centre of the earth decreases.

Above the surface, the weight decreases as the square of the distance from the centre of the earth increases.

64. Examples.—How much will a pound of iron weigh one thousand miles below the surface of the earth?

Ans.—As the iron would then be only three-fourths as far from the earth's centre, it would weigh only three-fourths as much, or twelve ounces.

How far below the surface of the earth will a ten-pound ball weigh only four pounds?

Ans.—As it is to weigh only $\frac{2}{5}$ as much, its distance from the earth's centre must be only $\frac{2}{5}$ of the earth's radius: $\frac{2}{5}$ of 4,000 miles is 1,600 miles. It will be 1,600 miles from the centre or 2,400 miles from the surface.

A body at the earth's surface weighs 900 pounds: What would it weigh 8,000 miles above the surface?

Ans.—It would then be 12,000 miles from the earth's centre or three times as far. The square of three is nine. According to the law above given, it would weigh only $\frac{1}{9}$ as much, or 100 pounds.

Experiment 34.—Six inches from the upper end of a string about two feet long, tie a small loop. Fasten any convenient weight, as an apple or large key, to the lower end of the string. Stick two stout pins or tacks into adjacent corners of the frame of your slate. Slip the loop over one pin and support the slate by the short part of the string, allowing the weight to hang free. When the slate and string have come to rest, mark a line on the slate, showing exactly the position of the string. Support the slate in a similar manner from the other pin and draw another line on the slate, again showing exactly the position of the string. Place your finger at the point where these two lines on your slate cross each other and balance the slate horizontally upon your finger tip.

65. Centre of Gravity. — *The centre of gravity of a body is the point about which all the matter composing the body may be balanced.*

A body thus balanced is said to be "in equilibrium."

The weight of a body may be supposed to be concentrated at the centre of gravity.

66. The Centre of Gravity may be Outside of the Body.—The centre of gravity may be outside of the matter of which a body consists, as in the case of a ring, hollow sphere, box, or cask. The same fact is illustrated by the "balancer," represented in Fig. 12. The centre of gravity is in the line joining the two heavy balls, *M M*, and thus under the foot of the waltzing figure.

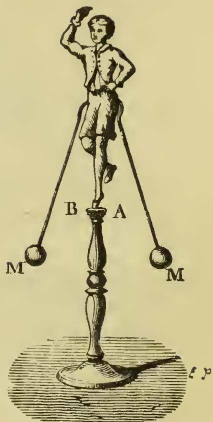

FIG. 12.

(*a.*) The "balancer" may be bought at the toy store for a few cents. The pupil may better make one, using a large cork for the body and a smaller one for the head. The neck, arms and legs may be made of stout pins, parts of hair-pins or other wire. The heavy balls may be two small potatoes. The uplifted arm may be made of extra length and serve as a staff for a paper flag, neatly colored with red and blue ink or pencil. Instead of using the heavy balls, the prongs of two forks or the open blades of two penknives, as shown in Fig. 13, may be thrust into the cork, the only thing necessary being to bring the centre of gravity lower down than the foot of the figure. *It is far better for the pupil to make his apparatus, when he can, than to buy it. He will understand more clearly, learn more rapidly, and soon enjoy the exercise of his ingenuity.* The remark applies to girls as well as to boys, and in many classes it happens that the girls are more ingenious and enterprising than the boys.

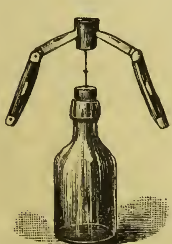

FIG. 13.

67. Equilibrium. — *When the centre of gravity is supported, the whole body will rest in a state of equilibrium.*

The centre of gravity will be supported when it and the point of support are at the same place or in the same vertical line.

(*a.*) A yard-stick may be supported by a needle thrust through its middle; the point of support and the centre of gravity are together.

(*b.*) It may be balanced with one end resting on the finger; the point of support and the centre of gravity are in the same vertical line, the latter being directly over the former.

(*c.*) It may be supported by hanging it by a string; the point of support and the centre of gravity are again in the same vertical line, the latter now being directly under the former.

(*d.*) The yard-stick in these three positions illustrates the three conditions or kinds of equilibrium.

68. Stable Equilibrium.—*A body supported in such a way that, when slightly displaced from its position of equilibrium, it tends to return to that position, is said to be in stable equilibrium.*

Such a displacement raises the centre of gravity. Examples: a disc or round flat plate supported above the centre; a semi-spherical oil-can; a pendulum or plumb-line. The cavalry-man represented in Fig. 14 may rock up and down balanced upon his horse's hind-feet, because the heavy ball brings the centre of gravity of the combined mass below the points of support. The "balancer" (Fig. 12) affords another example of stable equilibrium.

(*a*.) This apparatus is easily made. A piece of board an inch thick may be fashioned into a shape *something like* the body of a horse. The head and neck may be made of pasteboard. A feather makes a good tail and small nails answer admirably for legs. A potato or apple may be used for the heavy ball. The support may be made by placing a lath across the backs of two chairs. The "balancer" previously made may ride this bare-backed horse standing wherever he is placed, the weight of the apple and the length or curvature of the wire being varied to suit the circumstances.

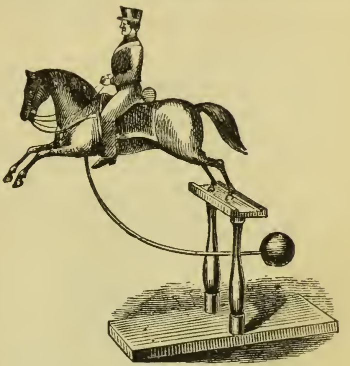

FIG. 14.

69. Unstable Equilibrium.—*A body supported in such a way that, when slightly displaced from its position of equilibrium, it tends to fall further from that position, is said to be in unstable equilibrium.*

Such a displacement lowers the centre of gravity. The body will not come to rest until the centre of gravity has reached the lowest possible point, when it will be in stable equilibrium. Examples: A disc supported below its centre; an egg standing on its end; a stick balanced upright upon the finger.

70. Neutral Equilibrium.—*A body supported in such a way that, when displaced from its position of equilibrium, it tends neither to return to*

its former position nor to fall further from it, is said to be in neutral or indifferent equilibrium.

Such a displacement neither raises nor lowers the centre of gravity. Examples: A disc supported at its centre; a sphere resting on a horizontal surface.

71. **Line of Direction.**—*A vertical line drawn downward from the centre of gravity is called the line of direction.*

It may be considered as a line connecting the centre of gravity of the given body and the centre of the earth.

72. **The Base.**—*The side on which a body rests is called its base.*

If the body be supported on legs, as a chair or table, the base is the figure formed by joining the points of support.

73. **Stability.**—*When the line of direction falls within the base, the body stands; when without the base, the body falls.*

When the body rests upon a point, as does the sphere, or upon a line, as does the cylinder, a very slight force is sufficient to move it, no elevation of the centre of gravity being necessary.

The broader the base and the lower the centre of gravity, the greater the stability.

(*a.*) These facts explain the stability of leaning towers like those of Pisa and Bologna. In some such towers the centre of gravity is lowered by using heavy materials for the lower part and light materials for the upper part of the structure.

(*b.*) It is difficult to stand upon one foot or to walk upon a tight rope because of the smallness of the base.

FIG. 15.

(*c.*) A porter carrying a pack is obliged to lean forward : a man carrying a load in one hand is obliged to lean away from the load, to keep the common centre of gravity of man and load over the base formed by joining the extremities of his feet.

74. Recapitulation.—To be amplified by the pupil for review

- **GRAVITATION.**
  - DEFINITION.
  - LAWS.
  - GRAVITY ....
    - DEFINITION.
    - WEIGHT ....
      - *Definition.*
      - *Law.*
    - CENTRE OF GRAVITY.
      - *What?*
      - *Where?*
    - EQUILIBRIUM.....
      - *Stable.*
      - *Unstable.*
      - *Neutral.*
    - STABILITY..
      - *Line of Direction.*
      - *Base.*

EXERCISES.

1. Why can a child walk more easily with a cane than without?

2. Why will a book placed on a desk-lid stay there while a marble would roll off?

3. Why is a pyramid a very stable form of structure?

4. Why is a ton of stone on a wagon less likely to upset than a ton of hay similarly placed?

5. If the weight of a body be doubled, what will be the effect on its attractive force?

6. If two bodies attract each other with a force of four units, what will be their attractive force when the distance between them is doubled?

7. How far does the earth's attraction extend?

SECTION III.

FALLING BODIES.

Experiment 35.—Drop a feather and a cent at the same time from the same height and notice that the cent will reach the ground first.

Experiment 36.—Take an iron and a wooden ball of the same size, drop them at the same time from an upper window and notice that they will strike the ground at nearly the same time. You will find that *it requires a little practice to drop them at exactly the same time.*

FIG. 16.

75. Velocities of Falling Bodies.—In Experiment 35, the cent fell faster than the feather, because it met with less resistance from the air than the feather did and *not because it was heavier.*

In Experiment 36, we made this resistance of the air nearly equal and, probably, convinced ourselves that the velocity of a falling body does not depend upon its weight, unless it has to overcome resistance, *or perform work,* while it is falling.

When the resistance of the air is removed, the feather and the cent will fall with equal velocities. This resistance may be avoided by trying the experiment in a glass tube from which the air has been removed. The experiment is difficult to perform and requires expensive apparatus. Fig. 16 shows the cent and the feather falling with equal velocities in a long tube from which the air has been removed with an air pump, an instrument that we shall soon consider. § 187.

76. Reason of this Equality.—The cent is heavier than the feather and is, therefore, pulled downward by a greater force. The iron ball has the greater weight, which shows that it is acted upon by a greater force than the wooden ball. But this greater force has to move a greater load, has to do more work than the lesser force.

For the greater force to do the greater work requires as much time as for the lesser force to do the lesser work.

A regiment will march a mile in no less time than a single soldier would do it; a thousand molecules can fall no further in a second than a single molecule can.

77. Gravity is a Constant Force.—In these experiments, the feather, the cent and the balls could not change from their condition of rest to that of motion by their own power (§ 22). It was necessary that some force act upon them to produce their motion. The force of gravity is what did the work.

During the first second, the force of gravity gave the falling ball a certain velocity; it gave the ball just as

much more velocity during the next second and just as much more during the third second. At the end of the third second, the ball was moving just three times as fast as it was at the end of the first second.

A force that thus continues to act uniformly upon a body, even after the body has begun to move, is called a constant force. Gravity is a constant force.

If gravity or any other constant force gives a body a velocity of 32 feet in one second, it will give a velocity of 64 feet in two seconds and a velocity of 96 feet in three seconds. The *increase* of velocity is 32 feet in each second.

78. Freely Falling Bodies.—When a falling body meets with no resistance, it is called a freely falling body. For heavy bodies, the resistance of the air is so little that it is generally left out of the account. A ball rolling down an inclined plane, can not be considered a freely falling body.

(*a.*) The laws of freely falling bodies have been very carefully studied. The apparatus used for this purpose is somewhat expensive. It is carefully described in the section on "Falling Bodies" in the author's *Elements of Natural Philosophy.*

79. Laws of Falling Bodies.—These laws are as follows:

(1.) *The velocity of a freely falling body at the end of any second of its descent is equal to 32.16 feet or 9.81 meters multiplied by the number of the second.*

(2.) *The distance traversed by a freely falling body during any second of its descent is equal to 16.08 feet or 4.9 meters multiplied by one less than twice the number of seconds.*

(3.) *The distance traversed by a freely falling body during any number of seconds is equal to 16.08 feet or 4.9 meters multiplied by the square of the number of seconds.*

80. Initial Velocity of Falling Bodies. — We have been considering bodies falling from a state of rest, gravity being the only force producing the motion. But a body may be thrown downward as well as dropped. In such a case, the effect of the throw must be added to the effect of gravity. If a body be thrown downward with an initial or starting velocity of fifty feet per second, we must add fifty feet to the result obtained under the first or second laws above or fifty feet multiplied by the number of the seconds to the result obtained under the third law.

81. Increment of Gravity.—Since gravity *increases* the velocity of a freely falling body 32.16 feet or 9.81 meters each second, this quantity is called the *increment* of velocity due to gravity or, more simply, the increment of gravity. In physical mathematics, it is generally represented by the letter g. *It must be remembered that $g = 32.16$ feet or 9.81 meters.*

82. Formulas.—If we represent the velocity at the end of any second by v, the number of seconds by t, the distance passed over each second by s, and the total space fallen through by S, we shall have the following formulas for freely falling bodies:

With no initial velocity.	*With 50 feet initial velocity.*
(1.) $v = gt$ or $\frac{1}{2}g \times 2t$.	$v = gt + 50$.
(2.) $s = \frac{1}{2}g\,(2t - 1)$.	$s = \frac{1}{2}g\,(2t - 1) + 50$.
(3.) $S = \frac{1}{2}g\,t^2$.	$S = \frac{1}{2}gt^2 + 50t$.

83. Recapitulation.—To be amplified by the pupil for review.

FALLING BODIES.
- IMPEDED; VELOCITIES VARY.
- FREELY FALLING.
  - DEFINITION.
  - VELOCITIES EQUAL.
- GRAVITY.
  - A CONSTANT FORCE.
  - CAUSES INCREMENT OF VELOCITY.
- EFFECTS OF INITIAL VELOCITY.
- LAWS AND FORMULAS.

EXERCISES.

1. How far will a body fall in 10 seconds? *Ans.* 1608 ft.

2. What velocity will a freely falling body attain in 4 seconds? *Ans.* 128.64 ft.

3. How far will a body move during the fourth second of its fall? *Ans.* 112.56 ft.

4. How far will a body move during the fifth second of its fall, if it starts with a velocity of 25 feet per second?

5. (*a.*) If a body rolling down an inclined plane gains a velocity of 10 feet in the first second, what will be its velocity at the end of the tenth second? (*b.*) What is its increment of velocity? *Ans.* (*a.*) 100 ft.

6. (*a.*) What is the increment of gravity in meters? (*b.*) In centimeters?

7. Two balls are dropped, one 3 seconds after the other. When the second one has fallen for two seconds, how far is it from the first? *Ans.* 337.68 ft.

8. A falling body has a velocity of 98.1 meters. How long has it been falling? *Ans.* 10 sec.

9. Show that the formula, $S = \frac{1}{2} gt^2$, given in § 82, is the same in meaning as the third law given in § 79.

SECTION IV.

THE PENDULUM.

84. The Pendulum. — *A common pendulum is a weight so suspended as to be capable of swinging to and fro.*

It appears in many forms. The most common form consists of a steel rod, thin and flexible at the top, carrying at the bottom a heavy mass of metal known as the *bob.*

85. Motion of the Pendulum. — When the supporting thread or bar of the pendulum is vertical, the centre of gravity is in the lowest possible position. The pendulum then remains at rest, for the force of gravity tends to draw it downward, thus producing pressure at the point of support but no motion. When the pendulum is drawn from its vertical position, the centre of gravity is raised. Gravity draws the pendulum back to a vertical position, when inertia carries it beyond until it is stopped and drawn back again by gravity. It thus swings to and fro in an arc.

Experiment 37. — In an open doorway or other convenient place, suspend a weight by a string or *fine* wire, four or five feet long. Swing this pendulum through an arc about a foot long and count the vibrations that it will make in a minute. Then swing the same pendulum through an arc two or three feet long and again count the vibrations that it will make in a minute.

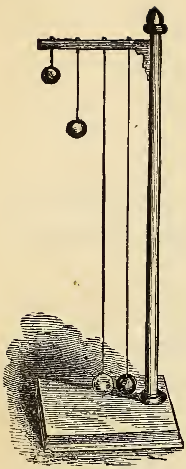

FIG. 17.

86. First Law of the Pendulum. — *The vibrations of a given pendulum, at any given place, are performed in equal times whether the arc be long or short.*

Experiment 38.—Provide another pendulum *of the same length* as the one used in the last experiment, but make it considerably heavier or considerably lighter. Remember that the true length of a pendulum is the distance between the point of support and a point near the centre of gravity, which latter point is called *the centre of oscillation.* Set both pendulums in vibration at the same time and notice whether the heavy or the light one vibrates the more rapidly.

87. Second Law of the Pendulum. — *The time of vibration is independent of the weight or material of the pendulum,* depending only upon the length of the pendulum and the intensity of the force of gravity at any given place.

Experiment 39.—Prepare two pendulums of such lengths that one shall vibrate just twice as often as the other. One will be several times as long as the other. *Find just how many times as long it is.*

Then prepare two pendulums, one of which shall vibrate just three times as often as the other and determine the ratio between their lengths as before.

Do the same thing with two pendulums, one of which vibrates four times as fast as the other. Place the ratios that you have found in the places of x, y and z in the following table:

Ratio of the Numbers of Vibrations.	*Ratio of Lengths.*
1	*1*
2	*x*
3	*y*
4	*z*
5	*?*
6	*?*

Can you see any law or rule governing in such cases? Try, without experiment, to put the proper numbers in the places of the two interrogation points. **Notice that the greater the length, the less the number of vibrations.**

88. Third Law of the Pendulum.—The vibrations of pendulums of different lengths are performed in different times. *The lengths are inversely proportional to the squares of the numbers of vibrations in a given time.*

$$L : l :: n^2 : N^2.$$

89. The Second's Pendulum.—*The length of a second's pendulum, at the level of the sea, is 39 inches at the equator; 39.2 inches, near the poles and about 39.1 inches or 993.3 millimeters or .9933 meters, in this latitude.*

As such a pendulum would be inconveniently long, use is generally made of one one-fourth as long which, consequently, vibrates half seconds.

The length and time of vibration of the second's pendulum being thus known, the length of any other pendulum may be found when the time of vibration is

given. The time of vibration may be found when the length is given.

(*a*.) The third law may be used in solving such a problem. It is interesting to notice how little difference there is between the length of a second's pendulum and the meter.

90. Use of the Pendulum in Time-pieces.—The motion of a clock is due to the force of gravity acting upon the weights, or to the elasticity of the spring. But the weights have a tendency toward accelerated motion (increasing velocity), while the spring would give an example of diminishing motion. Either defect would be fatal in a time-piece. Hence, the properties of the pendulum set forth in the first and third laws are used to *regulate* this motion and make it available for the desired end.

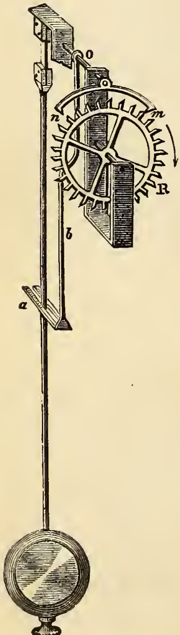

FIG. 18.

If the clock gains time, the pendulum is lengthened by lowering the bob; if it loses time, the pendulum is shortened by raising the bob.

Remember that the pendulum does not make the clock go; it simply determines *how fast* it shall run. It does this by means of the *escapement*, shown in Fig. 18. Every vibration of the pendulum works the *crutch*, *n m*, and allows the wheel, *R*, to move forward one tooth.

91. Recapitulation.—To be amplified by the pupil for review.

THE PENDULUM.

- DEFINITION.
- CAUSE OF VIBRATIONS.
- LAWS.........
  - FIRST.
  - SECOND.
  - THIRD.
- THE SECOND'S PENDULUM.
- APPLICATION TO CLOCKS.

EXERCISES.

1. If a pendulum swings through an arc two feet long, how many more times will it vibrate in a minute than when it swings through an arc four feet long?

2. One pendulum is 10 inches long and vibrates four times as fast as another. What is the length of the other?

3. Two pendulums are of the same length. The bob of one weighs a pound; that of the other, half a pound. Compare their rates of vibration.

4. One pendulum is 16 inches long; another is 64 inches long. How many times will the short one vibrate while the long one is vibrating four times?

5. What must you do to a pendulum to make it vibrate three times as fast?

6. A clock gains time. What is the trouble with its pendulum?

7. Two pendulums are 4 and 9 feet long respectively. How many vibrations will the short one make while the long one is vibrating twice?

8. Two pendulums are respectively 49 and 64 inches long. How will their times of vibration compare?

9. How long must a pendulum be to vibrate once in two seconds?

10. How long must a pendulum be to vibrate twice a second?

SECTION V.

ENERGY.

92. **Work.** — In physical science, the term *work signifies the overcoming of resistance* of any kind. Whether this overcoming of resistance is pleasant or not does not enter into consideration here, all *play* being a species of *work*. The word is here used in this enlarged sense.

93. **Energy.** — *Energy is the power of doing work.*

If one man can do more work than another, he has more energy. If a horse can do more work, in a given time, than a man, the horse has more energy than the man. If a steam-engine can do more work than a horse, it has more energy. If a moving cannon-ball can overcome a greater resistance than a base-ball, it has more energy.

94. **Elements of Work Measure.** — Imagine a flight of stairs, each step having a rise of twelve inches. On the floor at the foot of the stairs are a one pound weight and a ten pound weight. Lift the first weight to the top of the first step. How much work have you performed? Perhaps you will answer, one pound of work. Now place the second weight beside the first. How much work did you perform in so doing? Perhaps you will say ten times as much as before or ten pounds.

Now lift each of them another step, and then another, until they rest on the top of the tenth step. To lift the heavier weight the second, third and following times involved as much work each time as to lift it the first foot, but you would hardly say that you had lifted a hundred pounds.

Still it is sure that to place it on the tenth step required just ten times as much work as it did to place it on the first step or just one hundred times as much work as it did to place the one pound weight on the first step.

It is evident that the two elements of weight and height are necessarily considered in measuring the work performed.

95. Units of Work; the Foot-pound.—It is often necessary to represent work numerically and so we need a unit of measurement. The unit commonly in use, for the present, in England and this country is the foot-pound.

A foot-pound is the amount of work required to raise one pound one foot high against the force of gravity.

The work required to raise one kilogram one meter high against the same force is called a *kilogram-meter*.

(*a.*) To get a numerical estimate of work, we multiply the number of weight units raised by the number of units of length in the vertical height through which the body is raised. A weight of 25 pounds raised 3 feet, or one of 3 pounds raised 25 feet, represents 75 *foot-pounds*.

96. Rate of Doing Work. — In measuring work done, the time employed is not taken into consideration. In estimating the power that is to do the work, the time is an important element. Lifting a ton 100 feet high involves 200,000 foot-pounds, whether the work be done in ten minutes or ten hours. But the engine that can do this work in ten minutes is more powerful than one that requires ten hours.

97. Horse-Power. — *A horse-power represents the ability to perform 33,000 foot-pounds in a minute or 550 foot-pounds in a second.*

An engine that can do 66,000 foot-pounds in a minute or 33,000 foot-pounds in half a minute is called a two horse-power engine. To compute the number of horse-powers represented by an engine at work, multiply the number of pounds raised by the number of feet, and divide the product by 33,000 times the number of minutes required to do the work.

Experiment 40.—Into a pail full of moist clay or stiff mortar, drop a bullet from a height of one yard. Notice the depth to which the bullet penetrates. Drop the bullet from a height of four yards. It will strike the clay with twice the velocity (§ 79) and penetrate four times as far as it did before.

98. Relation of Velocity to Energy.—If the last experiment be continued by dropping the bullet from a height of nine yards, it would strike the clay with a three-fold velocity and penetrate to nine times the depth. The work done by a moving body will vary as the mass and as the square of the velocity.

(*a*.) The energy of a moving body may be computed in foot-pounds by multiplying the number of pounds in the moving body by the square of the number of feet it is moving per second and dividing the product by 64.32 (or twice the increment of velocity due to gravity, § 81).

$$\textbf{Kinetic Energy} = \frac{wv^2}{2g}.$$

NOTE.—For a fuller discussion of this subject, see the author's *Elements of Natural Philosophy*, § 157.

99. Two Types of Energy.—There are two kinds of energy. One is called *energy of motion;* the other, *energy of position.*

A falling weight or running stream possesses energy of motion; it is able to overcome resistance by reason of its weight and velocity.

But, before the weight began to fall, while it was at rest, it had the power of doing work by reason of its elevated *position* with reference to the earth. When the water of the running stream was at rest in the lake among the hills it had a power of doing work, an energy, which was not possessed by the waters of the pond in the valley below. This energy or power of doing work results from its peculiar position.

The weight or the water, when thus elevated and motionless, has no working power in the sense with which we are most familiar with it. Yet it is very clear that it is *possible,* under certain conditions, for it to do work. We might, therefore, use the term "possible energy" to denote the power in question and, as a matter of fact,

the term "potential energy," which means the same thing, is thus used.

Energy of motion is called kinetic energy; energy of position is called potential energy.

100. Convertibility of Kinetic and Potential Energies. — We may at any moment convert kinetic energy into potential, or potential energy into kinetic. One is as real as the other and, when it exists at all, exists at the expense of a definite amount of the other.

Imagine a ball thrown upward with a velocity of 64.32 feet. As it begins to rise it has a certain amount of kinetic energy because it has weight and velocity. At the end of one second it has a velocity of only 32.16 feet. Consequently, its kinetic energy has diminished. It has lost some of its velocity but it has gained a better position for doing work. Having risen 48.24 feet, it has gained a considerable potential energy. All of this potential energy results from the kinetic energy which has disappeared, or from the work that has been done.

At the end of another second the ball has no velocity; it has reached the turning-point and is at rest. Consequently, it has no kinetic energy. But the energy with which it began its flight has not been destroyed; it has been stored up in the ball at a height of 64.32 feet as potential energy. If at this instant the ball be caught, all of the energy may be kept in store as potential energy.

If now the ball be dropped, it begins to lose its potential and to gain kinetic energy. When it reaches the

ground at the end of two seconds it has no potential energy, but just as much of the kinetic type as was given to it when it began to rise.

In a simple way this illustrates the important fact that *energy may be changed from one form to another without any change in its quantity.*

101. Energy a Constant Quantity.—In the case of the ball thrown upward, at the start, at the finish or at any intermediate point of either its ascent or descent, the sum of the two types or kinds of energy is the same. It may be all kinetic, all potential, or partly both. In any case, *the sum of the two continually varying energies is constant.* Just as a man may have a hundred gold dollars, now in his hand, now in his pocket, now part in his hand and the remainder in his pocket; changing a dollar at a time from hand to pocket or *vice versa*, the amount of money in his possession remains constant, *viz.*, one hundred dollars.

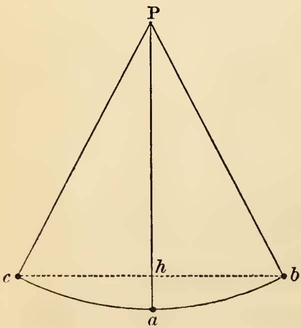

FIG. 19.

102. Pendulum Illustration.—The pendulum affords a good and simple illustration of kinetic and potential energy, and of their power of changing, one to another, without loss. When the pendulum hangs at rest in a vertical position, as P *a*, it has no energy at all.

Considered as a mass of matter, separated from the earth, it certainly *has* potential energy; but considered as a pendulum, it has no energy.

If the pendulum be drawn aside to *b*, we raise it through the space *a h*; that is, we do work, or spend kinetic energy upon it. The energy thus used is now stored up as potential energy, ready to be changed back into energy of the kinetic type, whenever we let it drop.

As it falls the distance *h a*, in passing from *b* to *a*, this change is going on. When the pendulum reaches *a*, its energy is all kinetic and just equal to that spent in raising it from *a* to *b*. This kinetic energy now carries it on to *c*, lifting it again through the space *ah*. Its energy is again all potential just as it was at *b*.

If we could free the pendulum from the resistances of the air and friction, the energy first given to it would swing to and fro between the extremes of *all potential* and *all kinetic;* but at every point of the arc traversed, the total energy would be an unvarying quantity, always equal to the energy first used in swinging it from *a* to *b*.

103. **Indestructibility of Energy.** — Were it not for friction and the resistance of the air, the pendulum would vibrate forever; its energy would be indestructible. Energy is withdrawn from the pendulum to overcome these impediments, but the energy thus withdrawn is not destroyed.

What becomes of it will be seen when we come to study heat and other forms of energy, which result from

the *motions and positions of the molecules* of matter. The truth is that *energy is as indestructible as matter.* For the present, we must admit that a given amount of energy may disappear and escape our search, but *it is only for the present.* We shall soon learn to recognize the fugitive even in disguise.

104. Recapitulation.—To be amplified by the pupil for review.

- **ENERGY.**
  - DEFINITION.
  - WORK.........
    - DEFINITION.
    - ELEMENTS....
      - *Weight.*
      - *Height.*
    - UNITS........
      - *Foot-pound.*
      - *Kilogram-Meter.*
      - *Horse-Power.*
  - RELATION TO VELOCITY,
  - TYPES.........
    - KINETIC.
    - POTENTIAL.
    - (KINETIC and POTENTIAL:) *Convertibility.*
  - INDESTRUCTIBILITY.

EXERCISES.

1. What is the necessary horse-power of an engine that is required to raise 100,000 pounds 198 feet high in one hour?

Ans. 10 H. P.

2. How long will it take a 2-horse-power engine to raise 10 tons 50 feet high?

3. How much must you increase the velocity of a moving body to quadruple its energy? *Ans.* 15 min., 10 sec., nearly.

4. How does the energy which a moving body must expend before it can come to rest compare in amount with the energy previously required to put the body in motion?

5. Define force and energy.

6. What amount of work is needed to lift 20 bricks weighing 5 pounds each 50 feet high?

7. (*a*.) How much work could the bricks mentioned in Exercise 6 perform in falling back to the ground? (*b*.) Where did they get that energy?

8. How much work may be done by a ball weighing 64,320 pounds and striking with a velocity of 200 feet a second?

Ans. 40,000,000 foot-pounds.

REVIEW QUESTIONS.

1. If a cork be released at the bottom of a vessel of water, it quickly rises to the surface. Explain the upward motion of the cork.

2. Give some illustration of unstable equilibrium not mentioned in this book.

3. Why does a wagon with a ton of hay overturn more easily than a similar wagon with a ton of stone?

4. In loading a wagon, where should the heavy articles be placed? Why?

5. Why do quadrupeds learn to walk more easily than bipeds?

6. Imagine a man suspended in otherwise empty space. Could he put himself in motion? Why?

7. If the distance between two bodies be doubled, how will their attraction for each other be affected?

8. What is meant by "increment of gravity"?

9. Why have liquids no permanent shape?

10. What property of steel fits it for use in pens?

11. What property of matter is illustrated in the action of the part of a watch that makes the wheels move?

12. What force resists our attempts to draw a nail out of wood?

13. What is the object of ballast in a vessel?

14. Thrust your hand into water and it comes out wet. What property of matter is illustrated by the experiment?

15. What is the cause of weight?

CHAPTER III.

SIMPLE MACHINES.

SECTION I.

PRINCIPLES OF MACHINERY.—THE LEVER.

Experiment 41.—Arrange two small pulleys and a spring-balance as shown in the figure. The pulleys and balance may be bought at the hardware store and will be much used. If *W* weighs 10 pounds, the spring-balance at *P* will show that the hand exerts a pull of 5 pounds. If the hand moves two feet it will be noticed that *W* moves one foot. No matter how far *P* moves; *W* will move just half as far *in the same time.* Under all circumstances, the product of the number representing the weight of *W* into the number representing the distance it moves, will equal the product of the number representing the weight (or pull) at *P* into the number representing the distance it moves. Change the positions of *P* and *W* and see if this is so.

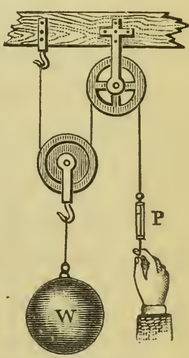

Fig. 19.

Note.—In this case, if the apparatus be delicate, it will be necessary to make an allowance for the weight of the cord and movable pulley. This allowance may be made by hanging just enough weight at *P* to keep the apparatus in

equilibrium before W is attached. In all experiments with pulleys, levers, and other machines, it is proper to see that *the machine itself is in equilibrium* before attempting to determine the relations of power to weight.

105. What is a Machine?—*A machine is a contrivance by means of which a given power may be used to overcome a given resistance with certain advantages.*

Its use is to transform the intensity of energy, so that an energy of small intensity, acting through a considerable distance, may be made to do the same work as a large power, acting through a small distance, or *vice versa.*

106. A Machine can not Create Energy.—No machine can create or increase energy. In fact, the use of a machine causes a waste of power, for a part of the energy must be used to overcome the friction of the machine itself, thus diminishing the amount that can be used for doing the work.

107. Of what Use are Machines?—Some of the many advantages resulting from the use of machines are:

(1.) *They enable us to do work more quickly than we otherwise could,* as in the sewing-machine or spinning-wheel.

(2.) *They enable us to do work that we otherwise could not do at all,* as in lifting a large stone with a crow-bar or pulleys.

(3.) *They enable us to change the direction of our force,* as in hoisting a flag on a flag-staff. It would be inconvenient to climb the pole and then draw up the flag.

(4.) *They enable us to employ other forces than our own,* as the strength of animals, the forces of wind, water, steam, *etc.*

108. General Laws of Machines.—The work to be done by a machine is generally called the weight or load. The work of the power (*e. g.*, foot-pounds) is always equal to the work of the load, the power expended in the machine itself being disregarded. The following are called the general laws of machines:

(1.) *What is gained in intensity of power is lost in time, velocity, or distance;* and what is gained in time, velocity, or distance, is lost in intensity of power.

(2.) *The power multiplied by the distance through which it moves, equals the weight multiplied by the distance through which it moves.* For example, if the power moves five times as far as the weight, the power will be only one-fifth as great as the weight.

(3.) *The power multiplied by its velocity, equals the weight multiplied by its velocity.* For example, if the power moves five times as fast as the weight, the power will be only one-fifth as great as the weight.

109. What is a Lever?—*A lever is an inflexible bar capable of being freely moved about a fixed point or line, called the fulcrum.*

Every lever has two arms. The power-arm is the perpendicular distance from the fulcrum to the line in which the power acts; the weight-arm is the perpendicular distance from the fulcrum to the line in which the weight acts.

110. Classes of Levers.—There are three classes of levers, depending upon the relative positions of the power, weight, and fulcrum.

(1.) If the *fulcrum is between* the power and weight (P. F. W.), the lever is of the first class (Fig. 20); *e. g.*, crow-bar, balance, steel-yard, scissors, pincers.

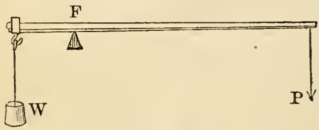

Fig. 20.

(2.) If the *weight is between* the power and the fulcrum (P. W. F.), the lever is of the second class, (Fig. 21); *e. g.*, cork-squeezer, nut-cracker, wheel-barrow.

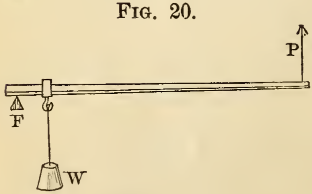

Fig. 21.

(3.) If the *power is between* the weight and the fulcrum (W. P. F.), the lever is of the third class (Fig. 22); *e. g.*, fire-tongs, sheep-shears, human fore-arm.

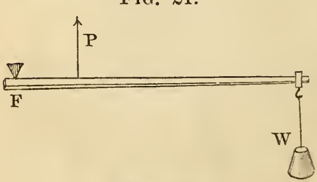

Fig. 22.

Experiment 42.—Bore a small hole 18 inches from one end of a yard-stick and nearer one edge than the other. Thrust a round metal pin through this hole into a firm vertical support, which may be made by nailing an inch board, 6 inches by 4 feet, to the side of a soap box and placing bricks in the box. Such a support will be convenient for many purposes. The pin should be of such a size as to move easily in the hole and yet have strength enough to carry a load of several pounds. It will be well to put a small metal washer on the pin between the yard-stick and the support. *Be sure that the stick is in equipoise* (or balances on the pin), shaving off the upper edge of the stick near one end if necessary for this purpose. Borrow, buy or (best of all) *make* two sets of weights of $\frac{1}{2}$ lb., 1 lb. and 2 lb. respectively. The weights may be provided with suspension loops of linen or silk thread, the weight of which may be disregarded.

(*a*.) Hang an 8 oz. weight on each side of the pin, 6 inches distant. **Notice that this lever of the first class balances;** then remove the weights.

(*b*.) Hang a 1 lb. weight on each side of the pin, 12 inches distant. **The lever balances.** Remove the weights.

(*c*.) Hang a $\frac{1}{2}$ lb. weight on one side of the pin 16 inches distant and a 1 lb. weight on the other side of the pin, 8 inches distant. **The lever balances.** Remove the weights.

(*d*.) Hang a $\frac{1}{2}$ lb. weight on one side of the pin 16 inches distant and a 2 lb. weight on the other side of the pin, 4 inches distant. **The lever balances.**

111. Static Laws of the Lever. — It will be clearly seen from the last experiment, that the following statements are true:

(1.) *The power multiplied by the power-arm equals the weight multiplied by the weight-arm; or,*

(2.) *A given power will support a weight as many times as great as itself, as the power-arm is times as long as the weight-arm.*

NOTE.—A static law expresses the relation between the power and weight when the machine is in equilibrium. In order that there be *motion*, one of the products mentioned in the law above must be greater than the other. The lever itself must be in equilibrium before the power and weight are applied. It is to be noticed that when we speak of the power multiplied by the power-arm, we refer to the abstract numbers representing the power and power-arm. We can not multiply pounds by feet, but we can multiply the number of pounds by the number of feet.

Experiment 43.—Make two scale-pans by hanging two tin can covers (each by three or four stout threads about a foot long) from the balanced yard-stick of Experiment 42. The upper ends of the cords of each pan may be knotted together and provided with a loop that will easily slide over the end of the yard-stick. Place one of these loops an inch from each end of the yard-stick and be sure that your scales balance well. Place an 8 oz. weight in one scale-pan and weigh out ½ lb. of sand.

112. The Balance.—*The balance is essentially a lever of the first class, having equal arms.*

Its use is to determine the weights of bodies. The lever itself is called the beam. The ends of the beam carry two pans, one to support the weights used, the other to support the article to be weighed. (Fig. 23.)

(*a.*) That the balance may be accurate, the arms must be of the same length. To make these arms *exactly equal* is far from an easy task. Balances are made so delicate that they may be turned by less than a thousandth of a grain. A really good balance is an expensive piece of apparatus and requires great care.

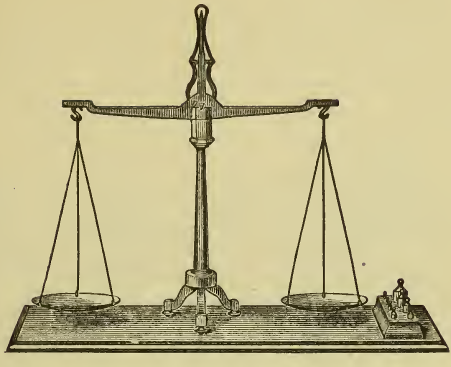

FIG. 23.

113. False Balances. — *False balances (levers of the first kind with unequal arms) are sometimes used by dishonest dealers.*

When buying, they place the goods on the shorter arm; when selling on the longer. The cheat may be exposed by changing the goods and weights to the opposite sides of the balance. The true weight may be found by weighing the article first on one side and then on the other, and taking the *geometrical* mean of the two false weights; that is, by finding the square-root of the product of the two false weights.

For instance, if the article appears to weigh eight pounds on one side and six pounds and two ounces on the other, the true weight is seven pounds.

$$8 \times 6\tfrac{1}{8} = 49. \quad \sqrt{49} = 7.$$

In buying seven pounds of butter, the dealer would pay for only six pounds and two ounces and, in selling the same butter, he would get pay for eight pounds, thus gaining, by fraud, the price of one pound and fourteen ounces, in addition to his legitimate profit.

114. Double Weighing. — The true weight of a body may be found with a false balance in another way. The article to be weighed is placed in one pan, and a counter-weight, as of shot or sand, placed in the other pan until equilibrium is produced. The article is then removed and known weights placed in the pan until equilibrium is again produced. These known weights will be the true weight of the given article.

115. Load between Two Supports. — *If a beam rest on two supports and carry a load between them, the beam may be considered a lever of the second class.*

The part carried by either support may be found by considering it as the power and the other support as the fulcrum. (Fig. 24.) For instance, if the string of fish weighs 15 pounds and is placed two feet from the boy in front and eight feet from the boy in the rear, we may want to know how much of the load the latter is carrying.

In this case, the shoulder of the boy in front is called the fulcrum. The weight-arm is two feet and the power-arm is ten feet. As the power-arm is five times as long as the weight-arm, the weight will be five

times the power or the power will be one-fifth the weight, *viz.*, three pounds. Of course, the boy in front carries the other twelve pounds of the load.

FIG. 24.

If we prefer, we may call the shoulder of the boy in the rear the fulcrum. In this case, the weight-arm is eight feet and the power-arm is ten feet. As the weight-arm is four-fifths as long as the power-arm, the power will be four-fifths of the weight, *viz.*, twelve pounds. Of course, the other three pounds is borne by the fulcrum, or the boy in the rear.

116. Compound Lever.—Sometimes it is not convenient to use a lever sufficiently long to make a given power support a given weight. A combination of levers called a compound lever may then be used. Hay-scales

may be mentioned as a familiar illustration of the compound lever. In this case we have the following:

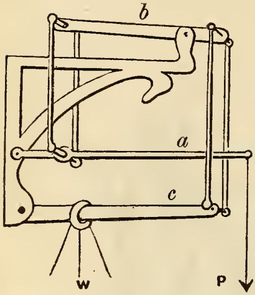

Fig. 25.

Statical Law. — *The continued product of the power and the lengths of the alternate arms, beginning with the power-arm, equals the continued product of the weight and the lengths of the alternate arms beginning with the weight-arm.*

(a.) If the arms of the lever, a, (Fig. 25) be $1\frac{1}{2}$ feet and 6 feet; of lever b, 1 foot and 3 feet; of lever c, 2 feet and 5 feet, a pull of 7 pounds at P will support a weight of 210 pounds at W.

$$7 \times 6 \times 3 \times 5 = 210 \times 2 \times 1 \times 1\tfrac{1}{2}.$$

117. Recapitulation.—To be amplified by the pupil for review.

- **MACHINES.**
  - DEFINITION.
  - NO CREATIVE POWER.
  - USES.
  - LAWS.

- **LEVER.....**
  - DEFINITION.
  - CLASSES.......
    - First: Balance...
      - *True.*
      - *False.*
      - *Double Weighing.*
    - Second: Load between Two Supports.
    - Third.
  - LAW.
  - COMPOUND.

EXERCISES.

1. The power-arm of a lever must be how many times as long as the weight-arm to have 100 kilograms support 1,000 kilograms?

2. Why is the short arm of a steelyard larger around than the long arm?

3. In Fig. 20, if the weight-arm is one foot and the lever is five feet long, what weight at W will be supported by a pull of seven pounds at P?

4. In Fig. 21, if the weight-arm is one foot and the lever is five feet in length, what weight at W will be supported by a pull of seven pounds at P?

5. In Fig. 22, if the power-arm is one foot and the length of the lever is five feet, what pull at P will be needed to support seven pounds at W? *Ans.* 35 lb.

6. A lever is 75 inches long. It enables a weight of one pound to balance a load of two pounds. Is the fulcrum in the middle? Why? If not, how far must the fulcrum be from the end of the lever?

7. The weight-arm of a lever is 6 feet long; the power-arm is 12 feet long. (*a.*) What is the length of the lever if it be of the first class? (*b.*) If of the second class? (*c.*) If of the third class?

8. Where must a straight bar be supported so that a pound weight hung at one end will support two pounds at the other end? *Ans.* At $\frac{1}{3}$ its length from one end.

9. The toggle joint shown in Fig. 26 and similar in action to those commonly used on carriage tops is used for punching iron. While the joint is moved from c to d, the punch b is moved forward until the distance ab becomes $ac + bc$. If $cd = 10$ inches; ab, $99\frac{1}{2}$ inches; ac and bc each, 50 inches and a power of 1,000 pounds pull c toward d, what force will be exerted upon the punch at b? *Ans.* 20,000 lb.

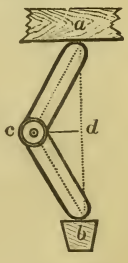

FIG. 26.

SECTION II.

THE WHEEL AND AXLE AND THE PULLEY.

118. The Wheel and Axle. — *The wheel and axle consists of a wheel united to a cylinder in such a way that they revolve together about a common axis.*

The power being applied to the circumference of the wheel, the load is carried by a rope wound around the axle.

119. Advantages of the Wheel and Axle.— The ordinary crowbar or other lever of the first class can lift a load only a short distance at one time. In order to raise the load higher than the vertical distance through which the weight end of the lever passes, it is necessary to support the load and readjust the fulcrum. The motion is irregular and time is lost. These difficulties are obviated by using the wheel and axle.

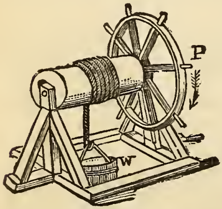

FIG. 27.

120. Law of the Wheel and Axle.—*The power multiplied by the radius, diameter or circumference of the wheel equals the weight multiplied by the corresponding dimension of the axle,* or,

The power will support a weight as many

times as great as itself, as the radius, diameter or circumference of the wheel is times as great as the similar dimension of the axle.

Example. — If the radius, diameter or circumference of the wheel is ten times as great as the similar dimension of the axle, the power will move ten times as far and ten times as fast as the weight and the weight will be ten times as great as the power. A power of 15 pounds will support a load of 150 pounds. See § 108, (2) and (3).

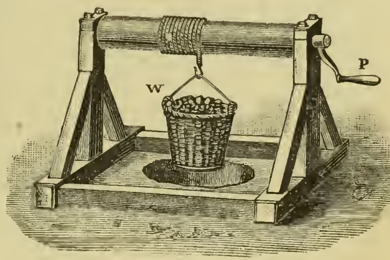

FIG. 28.

121. Various Forms of Wheel and Axle.— The wheel and axle appears in various forms. It is not necessary that an entire wheel be present, a single spoke or radius being sufficient for the application of the power, as in the case of the *windlass* (Fig. 28) or *capstan* (Fig. 29). In all such cases, the radius being given, the diameter or circumference of the wheel may be easily computed. (See Appendix *A*.)

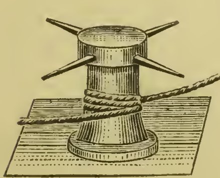

FIG. 29.

In one of the most common forms, the power is applied by means of a rope wound around the circumference of the wheel. When this rope is unwound by the action of the power, another rope is wound up by the axle and the weight thus raised.

122. Wheel-work.—Another method of securing a great difference in the intensities of balanced forces, is to use a combination of wheels and axles of moderate size. *Such a combination constitutes a train.* The wheel that imparts the motion is called the *driver;* that which receives it, the *follower.* An axle with teeth upon it is called a *pinion.* The teeth or cogs of a pinion are called *leaves.*

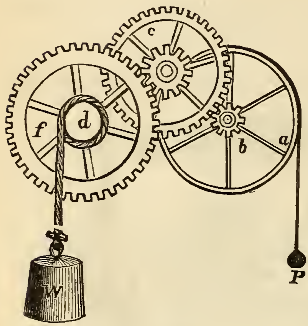

Fig. 30.

123. Ways of Connecting Wheels. — Wheels may be connected in three ways:

(1.) *By the friction of their circumferences.*

(2.) *By bands or belts.*

(3.) *By teeth or cogs.*

The third of these methods has been already considered.

124. Uses of the First Two Ways. — The first method is used where no great resistance is to be overcome but where evenness of motion and freedom from noise are chiefly desired. It is illustrated in some sewing-machines.

The second method is used when the follower is to be at some distance from the driver. The friction of the

belt upon the wheels must be greater than the resistance to be overcome. It is illustrated in most sewing-machines, in the spinning-wheel and, on a large scale, in every machine shop.

125. Relative Velocities Determined.—*The follower will revolve as many times as fast as the driver, as its radius, diameter or circumference is contained times in that of the driver.*

(*a.*) If the driver have a circumference of 10 feet and the follower a circumference of 2 feet, the follower will revolve 5 times as fast as the driver.

126. What is a Pulley?—*A pulley consists of a wheel turning upon an axis and having a cord passing over its grooved circumference.*

The frame supporting the axis of the wheel is called the *block*.

127. A Fixed Pulley.—If a cord be passed over a pulley fixed to the ceiling, a weight being at one end and the hand applied at the other, as at *P* in Fig. 31, the hand will have to exert a force equal to the weight of the load. If the weight be moved, the hand and weight will move equal distances. It is evident, then, that the *fixed pulley affords no increase of power, but only change of direction.*

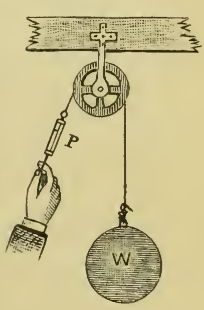

FIG. 31.

128. A Movable Pulley.—If one end of the cord be fastened to the ceiling, the load suspended from the pulley, and the other end of the cord drawn up by the hand or passed over a fixed pulley, as shown in Fig. 32, it will be evident that the fixed support (the hook) carries half the load and the hand the other half.

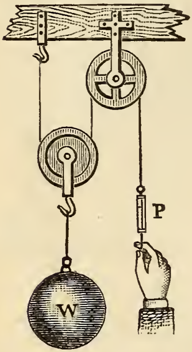

FIG. 32.

To raise the weight one foot, the hand must pull up two feet of the cord; that is to say, *each section* of the cord carrying the weight must be shortened one foot. Thus the hand, by pulling 50 pounds two feet, is able to raise 100 pounds one foot.

129. Advantages of the Pulley. — It is to be very carefully noticed that *the pulley does not create any energy or do any work.* It simply enables us to exchange velocity for intensity of work, and to change the direction in which the power acts.

If the hand at P pulls down with a force of 50 pounds and moves through a distance of four feet, it performs 200 foot-pounds of work. At the same time, the weight of 100 pounds will be raised two feet and this work is also represented by 200 foot-pounds.

It also requires *some additional power* to overcome the friction of the machine and to bend the ropes, but we probably would be glad to pay this price for the ability to exchange velocity which we can produce for the intensity which we desire.

130. A Combination of Pulleys.—By the use of several fixed and movable pulleys in blocks, the number of parts of the cord supporting the movable block may be increased at pleasure.

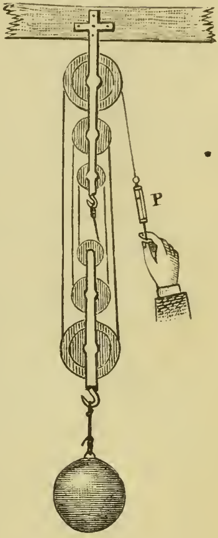

FIG. 33.

In all such cases, *the part of the cord to which the power is applied, will carry only a part of the load.* The value of this part of the load depends upon the number of sections into which the movable pulley divides the cord.

In Fig. 33, the movable pulley is represented as dividing the cord into six such parts. Then the power applied at P will support a load six times as great as itself.

In practice, the several wheels of each block are made of the same size and placed side by side, turning upon the same axis. The several wheels in a block are often called *sheaves.*

FIG. 34.

131. Law of the Pulley. — *With a pulley having a continuous cord, a given power will support a weight as many times as great as itself as there are parts of the cord supporting the movable block.*

132. Concerning the Number of Parts of the Cord.—Look at the several figures of

pulleys. You will see that when the fixed end of the cord is attached to the *fixed* block, the number of parts of the cord supporting the weight is twice the number of movable pulleys used.

When the fixed end of the cord is attached to the movable block, the number of parts of the cord is one more than twice the number of movable pulleys used.

133. Recapitulation.—To be amplified by the pupil for review.

- **WHEEL AND AXLE.**
  - DEFINITIONS.
  - ADVANTAGES.
  - RELATION TO THE LEVER.
  - LAWS.
  - FORMS.
  - WHEEL WORK...
    - DRIVER.
    - FOLLOWER.
    - CONNECTIONS. ...
      - *Modes.*
      - *Uses.*
    - RELATION OF P TO W.

- **PULLEY....**
  - DEFINITION.
  - KINDS.............
    - FIXED.
    - MOVABLE.
    - COMBINATIONS.
  - LAW.
  - NUMBER OF PARTS OF THE CORD.

EXERCISES.

1. If the wheel (Fig. 27) be 5 feet in diameter and the axle be 1 foot, what power must be exerted by the hand at P to support a load of 125 pounds at W? *Ans.* 125 lb.

2. If the handle of a windlass (Fig. 28) describes a circle 9 feet in circumference and thus causes the axle to wind up 3 feet of rope, what weight at W will be supported by every pound of force applied at P?

3. A ship's anchor, weighing two tons, is to be hoisted by a cable wound around the barrel of the capstan (Fig. 29). The barrel is two feet in diameter, A man pushes at the end of each of the four capstan bars (radii) which are eight feet long. With what force must each man push? *Ans.* 125 lb.

4. (*a.*) With such a pulley as is represented in Fig. 31, how great a load will a pull of 10 pounds support? (*b.*) How much with such a pulley as is represented in Fig. 32? (*c.*) How much with such a pulley as is represented in Fig. 33? (*d.*) How much with such a pulley as is represented in Fig. 34?

5. With such a pulley as is represented in Fig. 32, how great a load can a 100-pound boy *raise*?

Ans. A little less than 200 lb.

6. A man who weighs 180 pounds lifts a weight of 100 pounds by means of a fixed pulley over his head. What is the man's pressure on the floor? *Ans.* 80 lb.

7. A weight of 4 pounds is hung from the wheel which is 5 feet in diameter. A weight of 21 pounds is hung from the axle which is 1 foot in diameter. Which will descend, assuming that the wheel and axle works without friction?

SECTION III.

THE INCLINED PLANE, WEDGE, SCREW, ETC.

133. What is an Inclined Plane? — *The inclined plane is a surface sloping so as to make an oblique angle with the direction of the force to be overcome.*

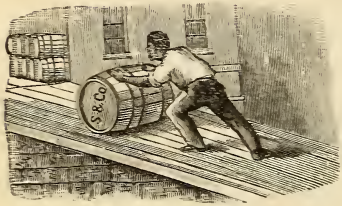

FIG. 35.

In most cases, it is used to aid in lifting bodies against the force of gravity.

134. Law for the Inclined Plane. — In Fig. 36, the plane is twice as long as it is high. As there indicated, a force of ten kilograms will support a weight twice as heavy. This result may be easily verified by experiment. We may establish the following law:

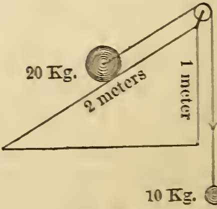

FIG. 36.

When a given power acts parallel to the inclined plane, it will support a weight as many times as great as itself as the length of the plane is times as great as its vertical height.

135. What is a Wedge?—*A wedge is a movable inclined plane.*

136. Its Use. — *The wedge is used for moving great weights short distances.*

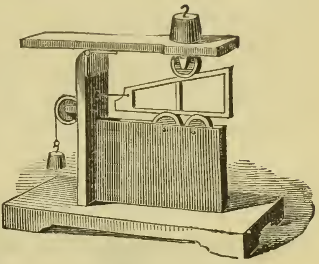

FIG. 37.

A common method of moving bodies is to place two similar wedges, with their thin ends overlapping, under the load. Blows of equal force are struck upon the heads of the wedges at the same time and the load is thus raised as shown by the arrows in Fig. 38.

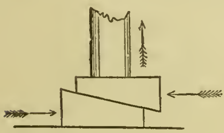

FIG. 38.

137. A More Common Use.—*A more common kind of wedge consists of two inclined planes united at their bases.*

Such wedges are used in splitting timber, stone, etc. The power is given in repeated blows instead of continued pressure. No definite law of any practical value can be given for the wedge, further than that, with a given thickness, the longer the wedge the greater the gain in intensity of power.

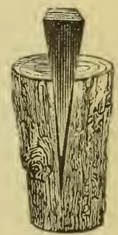

FIG. 39.

138. What is a Screw?—*A screw is a cylinder, generally of wood or metal, with a*

spiral groove or ridge winding about its circumference.

The spiral ridge is called the *thread* of the screw. The thread works in a *nut*, within which there is a corresponding spiral groove to receive the thread.

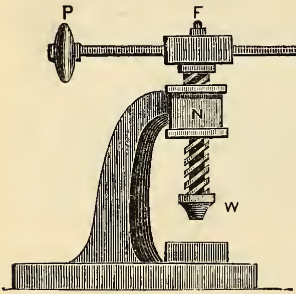

FIG. 40.

(*a.*) The power is used to turn the screw within a fixed nut, *N*, or to turn the nut about a fixed screw. In either case, a lever or wheel is generally used to aid the power. Every turn of the screw or nut either pushes forward the screw or draws back the nut by exactly the distance between two turns of the thread, this distance being measured in the direction of *F W*, the axis of the screw. The weight or resistance at *W* is moved this distance, while the power at *P* moves over the circumference of a circle whose radius is *P F*.

(*b.*) The circumference of the circle, or the distance that the power moves while the weight is being moved the distance between two turns of the same thread of the screw, may be found by multiplying two times *P F* (the diameter of the circle) by 3.1416. See Appendix A. The difference between these two distances is generally very great. Hence, this machine affords great intensity of power with a corresponding loss of velocity.

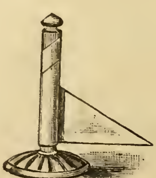

FIG. 41.

(*c.*) Figure 41 shows that **the screw is only a modified inclined plane.**

139. Law of the Screw. — *With the screw, a given power will support a weight as many times as great as itself as the circumference travelled over by the power is times as great as the distance between two adjoining turns of the thread.*

140. Compound Machines. — We have now considered each of the six simple machines. One of these may be made to act upon another of the same kind, as in the case of the compound lever or wheel-work; or upon another of a different kind, as in the case of the endless screw.

When any two or more of these machines are combined, the effective force may be found by computing the effect of each separately and then compounding them; or by finding the weight that the given power will support, using the first machine alone, considering the result as a new power acting upon the second machine, and so on.

141. An Example.—A horse is harnessed to the end of a capstan bar (Fig. 29) at a distance of 5 feet from the centre of the capstan barrel which is 15 inches in diameter. The rope wound upon the capstan barrel belongs to a system of two fixed and three movable pulleys. If the horse exerts a force of 500 pounds and we allow 25 *per cent.* for loss by friction, what force will be exerted upon the building which is being thus moved?

Solution.—The horse travels over the circumference of a circle 12 feet in diameter. In the mean time, the capstan will wind up a length of rope equal to the circumference of a circle 15 inches ($1\frac{1}{4}$ foot) in diameter. As the diameter or circumference of this larger circle is eight times as great as the diameter or circumference of the capstan barrel, the power moves eight times as far and eight times as fast as the weight does. Therefore the force exerted by the horse will be increased eightfold and the end of the rope will be pulled with a force eight times 500 pounds, or 4,000 pounds. This increased intensity of effort is the effect of the capstan alone.

By drawing a sketch or diagram of the pulleys, it will be seen that the fixed end of the rope must be attached to the fixed block and that there will be six parts of the rope acting upon the movable block and, thus, upon the weight. Then the pulley will increase the effect of the capstan sixfold.

4,000 lb. × 6 =	24,000 lb.
Deduct $\frac{1}{4}$ for loss by friction,	6,000 lb.
And we have left	18,000 lb.

as the force exerted by the compound machine.

(*a.*) The solution may be simplified as follows:

$$\frac{\overset{100}{\cancel{500}}\text{ lb.} \times 5 \times 2 \times \overset{3}{\cancel{12}} \times 6}{\underset{3}{\cancel{15}}} \times \frac{\cancel{3}}{\cancel{4}} = 18,000 \text{ lb.}$$

142. What is Friction? — *Friction is the resistance which a moving body meets from the surface on which it moves.*

143. The Cause of Friction.—It is impossible, by any known means, to produce a perfectly smooth surface. Even a polished surface contains minute projections which fit into corresponding depressions on the opposing surface. To produce motion of one surface on the other, these projections must be lifted out, bent down or broken off.

Friction is generally lessened by polishing and lubricating the surfaces that move upon each other and often by making the two bodies of different material. The axles of railway cars are made of steel, the boxes in which they turn are made of brass, the surfaces are made smooth and kept oiled. In spite of all of these precautions, the axle often becomes heated by friction to such an extent as to render it necessary to stop the train.

144. Friction is a Transformer of Energy.—Friction always develops heat: in other words, it converts mechanical energy into a familiar form of molecular energy. Whenever we find a loss of power through friction, we should bear in mind that the missing energy has not been destroyed. It has simply been transformed and still exists somewhere in the form of heat.

Energy, as well as matter, is continually changing its form but it can not be destroyed.

145. Recapitulation.—To be amplified by the pupil for review.

INCLINED PLANE.	DEFINITION. LAW.
WEDGE.	DEFINITION. TWO USES.
SCREW.	DEFINITION. LAW.
COMPOUND MACHINES;	RELATION OF *P* TO *W*.
FRICTION.	DEFINITION. CAUSE. REMEDY. EFFECT.

EXERCISES.

1. A boy who can lift only 100 pounds wishes to put a barrel of flour (196 pounds) into a wagon box 5 feet above the ground. He backs the wagon to one end of a plank 20 feet long and weighing 125 pounds. Show that he can, without help, use the plank as an inclined plane for his purpose and state how much force he exerts (*a.*) in getting the plank into position and (*b.*) how much in lifting the flour? *Ans.* (*a.*) $62\frac{1}{2}$ lb.; (*b.*) 49 lb.

2. How long must an inclined plane be that a force of 20 pounds may support a weight of 60 pounds, one end of the plane being 10 feet higher than the other end?

3. With apparatus arranged as shown in Fig. 33, the spring balance reads 15 pounds. What is the value of W?

4. A given screw has 4 threads to the inch. It is worked by a power that moves around a circle of 40 inches circumference. I wish to exert a pressure of 1,600 kilograms. How much power must I use? *Ans.* 10 Kg.

5. With the screw described in the last exercise, what pressure can be exerted by a power of 30 pounds, allowing $\frac{1}{10}$ of the same for friction? *Ans.* 4,320 lb.

REVIEW QUESTIONS.

1. How does the rising of a man in a small boat affect the stability of the boat? Why?

2. Why does a hand saw become warm when it is used?

3. On what two things does momentum depend?

4. Define the term *machine*.

5. What advantage is gained by the use of a fixed pulley?

6. What is the difference between adhesion and cohesion.

7. Tell what property of matter is affirmed in the declaration of "The Cloud":

> "I pass through the pores of the ocean and shores,
> I change but I can not die."

8. (*a.*) What two studies constitute physical science? (*b.*) Of what two subjects do they treat?

9. State the relative positions of the point of support and the centre of gravity in each of the three kinds of equilibrium.

10. Explain why a "running jump" is longer than a "standing" one.

11. (*a.*) Which is the more valuable, a lump of gold weighing, *on a spring balance*, one pound at the surface of the earth or a lump that would similarly weigh as much 1,000 miles above the surface? (*b.*) Why would not a lever balance (Fig. 23) answer for the comparison as well as a spring balance?

12. If the molecules of your body do not touch one another, why is it that the wind does not blow you away in the form of fine dust?

13. What force must be overcome in order to scratch a substance?

14. Dip a glass rod into mercury and tell which is the stronger, the adhesion of the liquid for the rod or the cohesion of the liquid molecules?

15. Show that in lifting at the end of the plank mentioned in Exercise 1, page 93, the plank represented a lever of the second class, and indicate the positions of P, F and W.

16. (*a*.) When water is poured from a jar, it often runs down the inclined side of the vessel instead of falling vertically. What force draws the falling water from a vertical course? (*b*.) Can you suggest a way to prevent such a result?

17. If a stone weighs 10 pounds at the level of the ocean, how much will its weight measure, by a spring balance, 1,000 miles nearer the centre of the earth?

18. Why is it easier to roll a sphere than a cube?

19. What is a foot-pound? A kilogram-meter? A horse-power?

20. Find the kinetic energy of a 100-pound ball moving with a velocity of 2,000 feet a second.

21. Imagine a boy motionless in empty space. Can he put himself in motion?

CHAPTER IV.

LIQUIDS.

SECTION I.

LIQUID PRESSURE.

Experiment 44.—Fill a small bottle with water, hold a Prince Rupert drop in its mouth and break off the tapering end of the "drop." The whole "drop" will be instantly shattered and the force of the concussion transmitted in every direction to the bottle which will be thus broken.

These "drops" are not expensive and may be obtained from JAMES W. QUEEN & Co., Philadelphia.

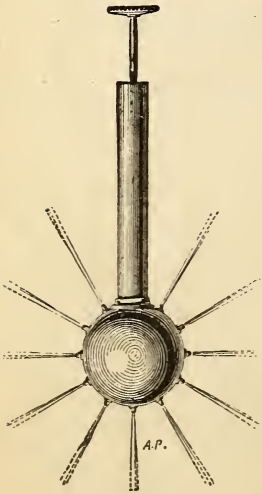

FIG. 42.

146. Transmission of Pressure.—*Fluids transmit pressure in every direction, upward, downward, and sidewise at the same time.*

(*a.*) This property of liquids may be illustrated by the apparatus represented in Fig. 42. The globe and cylinder being filled with water and the several openings in the globe closed by corks, a piston is pushed down the cylinder. The pressure thus received and transmitted by the confined water

expels the cork and throws a jet of water from each aperture and not merely from the one opposite the piston.

(*b.*) Figure 43 represents a corked bottle of water. When the cork is forced downward, it exerts pressure upon all the water molecules in contact with it. These transmit the pressure to every part of the inner surface of the glass. Every part of this surface equal in area to that of the end of the cork will be subjected to a pressure like that exerted by the cork. The pressure acts in a direction perpendicular to the surface of the glass, as shown by the arrows in the figure.

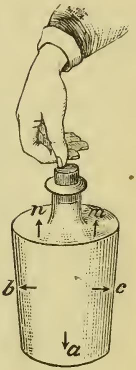

FIG. 43.

(*c.*) It must be remembered that fluids include both aëriform and liquid bodies. Aëriform bodies are largely compressible; liquids are nearly incompressible.

147. Pascal's Principle.—*When fluids are subjected to pressure, the pressure sustained by any part of the restraining surface is perpendicular to it and proportional to its area.*

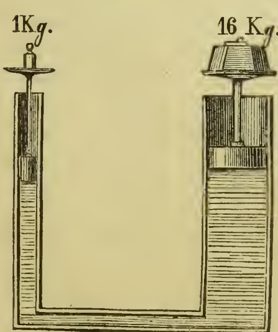

FIG. 44.

This may be shown by experiment as follows:

Provide two communicating tubes of unequal sectional area. When water is poured into these, it will stand at the same height in both tubes. If the water in the smaller tube be subjected to pressure by means of a

piston, the water will be forced back into the larger tube. To prevent this result, a piston must be fitted to the larger tube and held there with a force as many times as great as the force acting upon the other piston as the area of the larger piston is times as great as the area of the smaller one.

If, for example, the smaller piston have an area of 1 square inch and the larger piston an area of 16 square inches, a weight of 1 kilogram or ounce may be made to support a weight of 16 kilograms or ounces. Of course, the weight here referred to includes the weight of the piston itself in each case.

(*a*.) It is evident that in this experiment it will be difficult to get the pistons to work without considerable friction. For this reason, the experiment is sometimes modified and simplified by filling the lower part of the tubes with mercury, which will stand at the same level in both arms. If water be poured into the smaller tube it will depress the mercury surface in that tube ; 16 times the weight of water must be poured into the larger tube to restore the two mercury surfaces to the same level.

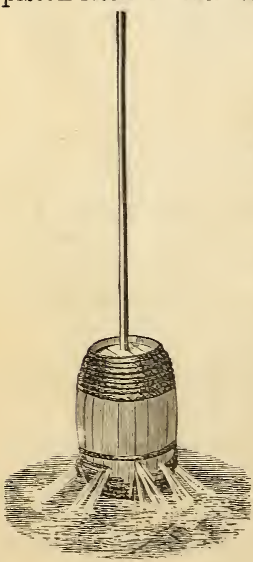
Fig. 45.

148. Pascal's Experiment.—Pascal firmly fixed a very narrow tube about 30 feet high into the head of a stout cask. He then filled the cask and tube with water. The weight of the small amount of water in the tube actually burst the cask.

149. The Hydrostatic Bellows. — *The hydrostatic bellows consists of two boards fastened together by a broad band of stout leather and a small vertical tube communicating with the interior.*

In the figure, the tube that bears the funnel is to be joined to the tube passing upward from *b*. This vertical tube may be filled with water and the pressure thus exerted will lift a heavy weight (*e. g.*, several boys) placed upon *B*.

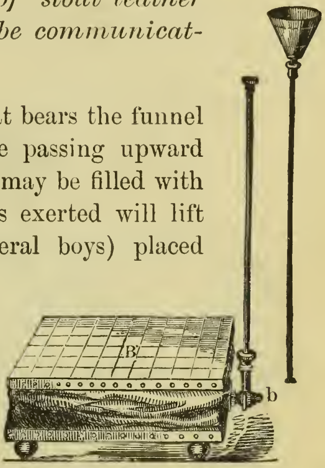

Fig. 46.

If the board, *B*, has a surface of 66 square inches exposed to the upward pressure of the water in the bellows and the tube have a sectional area of $\frac{1}{4}$ square inch, every pound of water in the tube will support 264 pounds at *B*.

150. The Hydrostatic Press. — The hydrostatic press acts upon the same principle. It is represented in perspective by Fig. 47 and in section by Fig. 48. Pressure is produced by the force-pump *A*. The substance to be pressed is placed between *K*, the head of the piston, and an immovable plate *M N*. The reservoir, *B*, and the cylinder of the pump, are connected by the tube *d*. By the action of the pump, the water in the cylinder *A* is subjected to pressure and this pressure is transmitted undiminished to the water in *B*. The piston, *a*,

is generally worked by a lever of the second class, resulting in a still further gain of intensity of power.

If the power-arm of the lever be ten times as long as the weight-arm, a power of 40 pounds at the end of

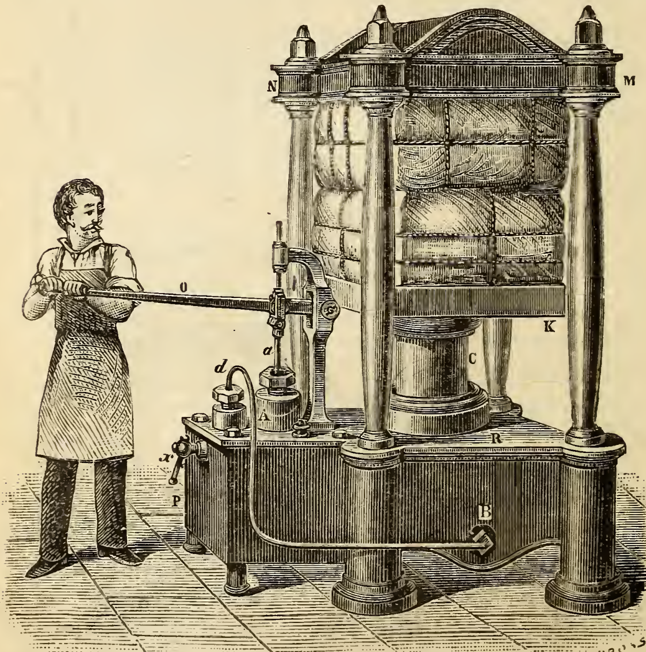

Fig. 47.

the lever will exert a pressure of 400 pounds upon the water in *A*.

If the piston in *A* have a sectional area of 1 square inch and the piston in *B* have an area of 500 square

inches, then the pressure of 500 pounds exerted by the small piston will produce a pressure of 400 pounds × 500 or 200,000 pounds upon the lower surface of the large piston. Hence the following rule :

Multiply the pressure exerted by the piston of the pump by the ratio between the sectional areas of the two pistons.

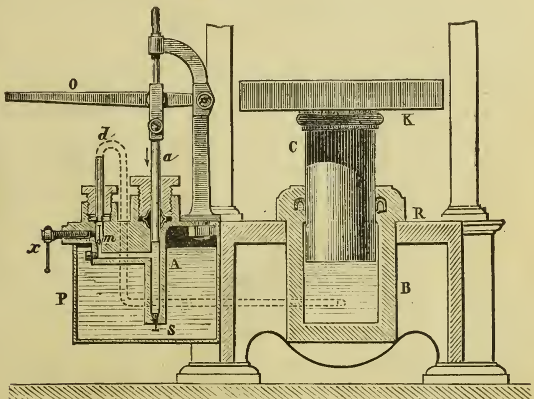

Fig. 48.

Experiment 45.—Over the opening of a wide mouthed bottle or fruit jar, tie a piece of thin sheet rubber. Hold the bottle in a tub of water with the mouth downward, sidewise and upward. In each case, the pressure of the water will force the rubber inward. Try the experiment at different depths of water and notice that **the pressure will vary with the depth.**

151. Liquid Pressure Due to Gravity.—The pressure exerted by liquids, on account of their weight, may be downward, upward, or lateral. We shall now briefly consider these three kinds of liquid pressure.

Experiment 46.—Into a bent glass tube, *A B C*, pour mercury (quicksilver) until it covers the bend and rises two or three inches above it. The mercury will stand at the same level, *a c*, in the two branches of the tube. If pressure of any kind be exerted upon the surface of the mercury at *a*, it will be promptly shown by the movement of the mercury and a consequent difference in the heights of the two mercury columns. The greater the pressure, the greater will be the elevation of *c* above the level of *a*.

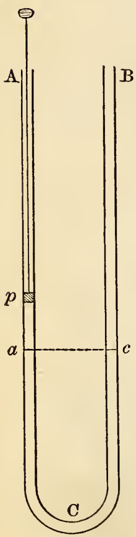

FIG. 49.

A common glass funnel or a piece of glass tube may be joined to *A* by a short piece of snugly fitting rubber tubing. Suppose the funnel to be thus connected and the apparatus supported by any convenient means in an upright position. Pour water into the funnel and mark the level of the water by a suspended weight or other means; mark the level of the mercury in the long arm of the tube by a string or small elastic band.

Remove the funnel and connect the straight glass tube above *A*. Fill this with water to the same height as before, as indicated by the suspended weight. Although the quantity of water used is much less, the depression of the mercury at *a* and its elevation at *c* will be the same as before, showing the downward pressure at *a* to be the same in both cases Directions for bending glass will be found in *Chemistry*, Appendix 4.

152. Downward Pressure.—*The pressure on the bottom of a vessel containing a liquid depends upon the depth and density of the liquid and the area of the bottom.*

The quantity of the liquid and the shape of the vessel make no difference.

153. Rule for Downward Pressure. — *To find the downward pressure on a horizontal surface, find the weight of an imaginary column of the given liquid, with a base the same as the given surface and an altitude the same as the depth of the given surface below the surface of the liquid.*

NOTE.—A cubic foot of water weighs about 1,000 ounces, $62\frac{1}{2}$ pounds (more exactly 62.42 pounds).

154. Example.—A cask has a base of 3 square feet and a height of 2 feet. A tube is fitted into the upper head. The cask is filled with water; more water is then added until the tube is filled to a height of 3 feet above the upper head. What is the pressure on the lower head of the cask?

Solution.—Our "imaginary column" of water has a base of 3 square feet and a height of 5 feet. It therefore has a volume of 15 cubic feet. The weight of the "imaginary column" of water would be 15 times 62.42 pounds or 936.3 pounds. This is the pressure exerted upon the lower end of the cask.

Although the quantity of water actually used is less than half that of our "imaginary column," the pressure exerted by it is the same as explained in § 152. If a liquid like alcohol had been used, the pressure would have been only about $\frac{8}{10}$ of 936.3 pounds, for alcohol is only about $\frac{8}{10}$ as heavy as water. If the liquid used had been mercury, which is 13.6 times as heavy as water, the pressure would have been 13.6 times 936.3 pounds or 12,733.68 pounds—*more than six tons.*

NOTE.—In all such cases the pupil may be allowed to use $62\frac{1}{2}$ pounds as the weight of a cubic foot of water if he prefers to do so. That value (1,000 ounces) is more easily remembered.

Experiment 47.—Make a small hole in the bottom of a tin fruit can or similar vessel. Push the can downward into water until the open mouth of the can is "near the water's edge." The liquid will spurt upward through the hole in a little jet.

155. Rule for Upward Pressure.—*To find the upward pressure on any horizontal surface, find the weight of an imaginary column of the given liquid with a base the same as the given surface and an altitude the same as the depth of the given surface below the surface of the liquid.*

156. Example.—What will be the upward pressure on a horizontal plate a foot square when placed 10 feet beneath the surface of water?

Solution.—The volume of our "imaginary column" of water is 10 cubic feet. It would weigh 10 times 62.42 pounds or 624.2 pounds. Consequently, the upward pressure would be 624.2 pounds.

157. Rule for Lateral Pressure. — *To find the pressure upon any vertical surface, find the weight of an imaginary column of the liquid with a base equal to the given surface and an altitude the same as the depth of the centre of the given surface below the surface of the liquid.*

158. Example.—A dam is 25 feet high and 30 feet long. Water stands at a height of 20 feet on one side of the dam. What is the liquid pressure on the dam?

Solution.—The dam may be vertical or sloping, but in either case, the surface *that we have to consider* is 20 feet high and 30 feet long. The depth of its centre below the surface of the water is 10 feet. Our "imaginary column" will, therefore, have a volume of 6,000 cubic feet and a weight of 374,520 pounds. The pressure will, therefore, be 374,520 pounds.

159. Recapitulation.—To be amplified by the pupil for review.

LIQUID PRESSURE.
- TRANSMITTED EQUALLY IN ALL DIRECTIONS.
- EFFECT ON RESTRAINING SURFACE.
  - Pascal's Experiment.
  - Hydrostatic Bellows.
  - Hydrostatic Press.
- PRODUCED BY GRAVITY............
  - *Rules.*
    - Downward.
    - Upward.
    - Lateral.

EXERCISES.

1. Referring to Fig. 48, suppose the area of the end of piston, *a*, to be 1 square inch and that of piston, *C*, to be 10,000 square inches and the two arms of the lever, *O*, to be 1 foot and 10 feet respectively, what pressure at *K* will be produced by a pressure of 100 pounds by the operator? *Ans.* 10,000,000 lb.

2. Where will water issue from a water pipe with the greater force, in the basement or near the top of a house? Why?

3. Find the pressure on a dam 25 feet long, the water being 10 feet deep? *Ans.* 80525 lb.

4. A tank has a base 6 feet by 8 feet. What is the pressure on that base when the water in the tank is 4 feet deep? *Ans.* 12368.64 lb.

5. A tank has a base 2 meters by 3 meters. What is the pressure on that base when the water in the tank is 1.5 meters deep? *Ans.* 9000 Kg.

SECTION II.

EQUILIBRIUM.—BUOYANCY.

160. Equilibrium of Liquids.—A liquid of small surface is said to be level when all the points of its surface are in the same horizontal plane. The central idea is expressed in the familiar saying, *water seeks its level.* This is true whether the liquid be placed in a single vessel or in several vessels that communicate with each other.

Experiment 48.—Incline a tea-pot that is nearly full of water until the liquid begins to run out at the spout. Notice that **the end of the spout and the water surface in the vessel are at the same level.**

161. Communicating Vessels.—When a liquid is placed in one or more of several vessels communicating with each other, *it will not come to rest until it stands at the same height in all of the vessels.*

Experiment 49.—From one end of a scale-beam, suspend a cylindrical bucket of metal, *b*, and below that a solid cylinder, *a*, which accurately fits into the bucket. Counterpoise with weights in the opposite scale-pan. Then place a vessel of water, as shown in Fig. 50, so as to immerse *a* and the counterpoise will descend, showing that *a* has lost some of its weight. Carefully fill *b* with water. It will hold exactly the quantity displaced by *a*. **Equilibrium will be restored.** The bucket and cylinder may be had of dealers in philosophical apparatus.

Experiment 50.—Insert a short spout in the side of a vessel (as a tin fruit-can) about an inch below the top. Fill the vessel with water and let all above the level of the spout escape. This is to replace the vessel of water in which *a* (Fig. 50) is immersed. Instead of the bucket, *b*, use a cup placed on the scale-pan. Instead of *a*, use any convenient solid heavier than water, as the fragment of a stone, which may be suspended by a horse-hair or a fine thread. Counterpoise the cup and stone in the air. Immerse the

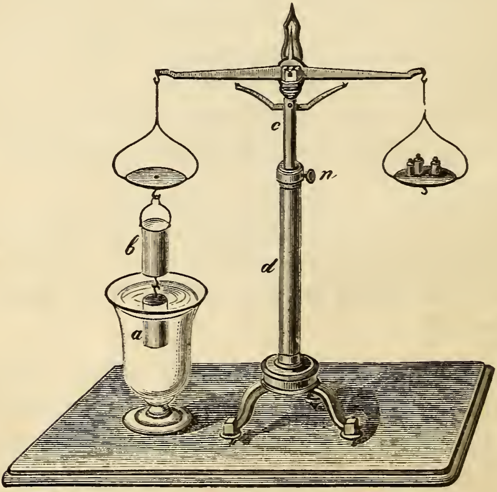

Fig. 50.

stone in the water and catch, in any convenient vessel, every drop of water that overflows. This will be the fluid that the solid displaces. The equilibrium is destroyed, but may be restored by pouring the water just caught into the cup on the scale-pan. It may sometimes be necessary to make allowance for the small quantity of water that adheres to the cup in which the overflow was caught, but with a good balance and *good work* the result will clearly show the truth of *Archimedes' Principle.*

162. Archimedes' Principle.—It is a familiar fact that a person may easily raise to the surface of the water a stone which he can not lift any further. When an arm or leg is lifted out of the water of a bath-tub, it suddenly feels heavier. Many such facts are explained by the important principle here given :

The loss of weight of a body immersed in a fluid equals the weight of the fluid which it displaces.

Experiment 51.—Place the tin vessel with a spout, mentioned in Experiment 50, upon one scale-pan, and fill it with water, some of which will overflow through the spout. When the spout has ceased dripping, counterpoise the vessel of water with weights in the other scale-pan. Place a floating body on the water. This will destroy the equilibrium but water will overflow through the spout until the equilibrium is restored. **This shows that the floating body has displaced its own weight of water.**

Experiment 52.—Place a fresh egg in a vessel of fresh water; it is a little heavier than the water and will sink. Place it in salt water; it is a little lighter than the brine and will float. Carefully pour the fresh water on the salt water in a tall, narrow vessel like that shown in Fig. 000. Place the egg in the water; it will descend until it reaches a layer of the liquid with a density like its own and **there it will float.**

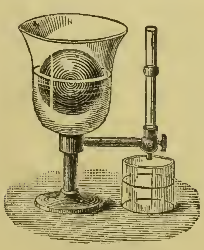

FIG. 51.

163. Floating Bodies. — *A floating body displaces its own weight of the fluid on which it floats.*

This may be shown experimentally by filling a vase with water. When a floating body is

placed on the surface, the water displaced will overflow and may be caught. The water thus caught will weigh the same as the floating body.

(*a.*) If a body placed on the surface of a fluid can not displace its own weight of the fluid, it will sink and not float. The buoyant effect of the fluid is then less than the weight of the body. Sometimes a heavy substance has such a shape that it will displace enough of a lighter fluid to float thereon. For this reason, an iron kettle or an iron ship will float on water, although iron is several times heavier than water. In all such cases, **the buoyant effect of the fluid equals the weight of the floating body.**

(*b.*) Just as the gravity of a body may be considered as acting upon a single point called the centre of gravity, so the buoyant effort of a fluid may be considered as acting upon a single point called the centre of buoyancy. **The centre of buoyancy is situated at the centre of gravity of the displaced fluid.**

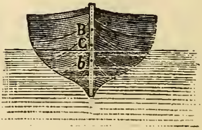

FIG. 52.

(*c.*) The centre of buoyancy may be considered the point of support of the floating body and the principles of §§ 65–68 applied anew. For example, if the boat's centre of buoyancy be at C and its centre of gravity be at b (as it may be if its occupant is sitting down), the boat will be in stable equilibrium, while if its centre of gravity be at B (as it may be if its occupant is standing up), **the boat will be in dangerously unstable equilibrium.**

164. Recapitulation.—To be amplified by the pupil for review.

- **LIQUID EQUILIBRIUM.**
  - FAMILIAR SAYING.
  - IN COMMUNICATING VESSELS.
- **BUOYANCY.** ....
  - ARCHIMEDES' PRINCIPLE.
  - FLOATING BODIES....
    - DISPLACE WHAT?
    - EFFECT OF SHAPE.
    - CENTRE OF BUOYANCY.
      - *Stable Equilibrium.*
      - *Unstable Equilibrium.*

EXERCISES.

1. Where are water pipes of uniform strength connected with the same reservoir more likely to burst, on a hill or in a valley? Why?

2. What weight of water will a 50-pound canoe displace?

3. What weight of water will a cubic foot of iron displace?

4. How much weight will a cubic foot of lead lose when it is placed in water?

5. Do you know anything about the personal history of Archimedes?

6. How much water will a board displace, (*a.*) when it floats on the surface? (*b.*) When it is held under the surface?

7. When is a boat in stable equilibrium?

8. In lifting a pail of water from a cistern, it does not seem heavy until it is raised out of the water. Why is this?

9. Why is it difficult to stand in water reaching to your chin?

SECTION III.

SPECIFIC GRAVITY.

165. What is Specific Gravity? — *The specific gravity of a body is the ratio between its weight and the weight of a like volume of some other substance taken as a standard.*

It is an abstract number and shows *how many times* the weight of a body will contain the weight of the same volume of some other substance that is taken as a standard.

166. Standards of Specific Gravity.—*For solids and liquids, the standard adopted is distilled water at a temperature of 4° C., or 39.2° F.*

For aëriform bodies, the standard is air or hydrogen.

167. Elements of the Problem. — *For solids or liquids, the dividend is the weight of the given body; the divisor is the weight of the same bulk of water; the quotient, which is an abstract number, is the specific gravity.*

The weight of the same bulk of water is found sometimes in one way and sometimes in another but, *in every case, it is the divisor.* By grasping and keeping this idea, you will avoid much possible confusion. Of course, when any two of these three are given, the third can be found.

168. To Find the Specific Gravity of Solids.— The most common method of finding the specific gravity of a solid heavier than water, is to find the weight of the body in the air ($= W$), then suspend the body by a light thread and find its weight in water ($= W'$), and divide the weight of the body in air by the weight of the same bulk of water (§ 162, Archimedes' Principle).

$$Sp.\ Gr. = \frac{W}{W - W'}.$$

(*a*.) The method is illustrated by the following example:

Weight of substance in air	$= 58\frac{1}{2}$ oz.
Weight of substance in water	$= 51$ oz. (Fig. 54).
Weight of equal bulk of water	$= 7\frac{1}{2}$ oz.

Specific gravity $= 58\frac{1}{2}$ oz. $\div\ 7\frac{1}{2}$ oz. $= 7.8$, *Ans.*

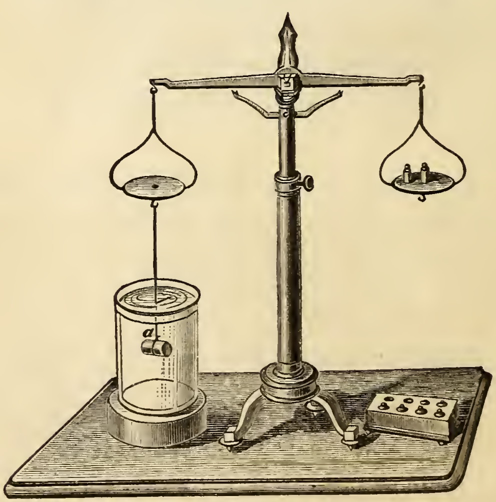

FIG. 53.

169. To Find the Specific Gravity of Liquids.—The principle is unchanged. A simple method is as follows:

Weigh a flask first empty; next, full of water; then, full of the given liquid. Subtract the weight of the empty flask from the other two weights; the results represent the weights of equal volumes of the given substance and of the standard. Divide as before.

(*a.*) A flask of known weight, graduated to measure 100 or 1,000 grams or grains of water is called a *specific gravity flask.* Its use avoids the first and second weighings above mentioned and simplifies the work of division.

(*b.*) The specific gravity of a liquid may be easily determined as follows:

Find the loss of weight of any insoluble solid in water and in the given liquid. Remember (§ 162) what these two losses represent. Divide as before. The solid used is called a *specific gravity bulb.*

(*c.*) The determination of the specific gravity of gases presents many practical difficulties which can not be considered in this place.

170. Recapitulation.—To be amplified by the pupil for review.

SPECIFIC GRAVITY.
- DEFINITION.
- STANDARDS.
- DIVIDEND AND DIVISOR.
- OF SOLIDS.
- OF LIQUIDS..................
  - SPECIFIC GRAVITY FLASK.
  - SPECIFIC GRAVITY BULB.

EXERCISES.

1. A body weighs 150 pounds in air and 100 pounds in water. What is its specific gravity?

2. A body weighs 75 ounces in air and 60 ounces in water. What is the weight of an equal bulk of water?

3. Lead has a specific gravity of about $11\frac{1}{3}$. Mercury is a liquid having a specific gravity of about $13\frac{3}{5}$. Will lead sink in mercury?

4. Sulphuric acid has a specific gravity of 1.8. Will a glass ball lose more weight in the acid than it will in water?

5. In which will a body weigh more, in fresh water having a specific gravity of 1 or in sea water having a specific gravity of 1.026?

6. Is it, then, easier for a person to float in fresh water than it is in sea water?

7. A piece of brass weighing 41.9 ounces was placed in a vessel full of water. The overflowing water was caught and found to weigh 5 ounces. What is the specific gravity of brass?

Ans. 8.38

8. A liter bottle holds 1,000 grams of water or 800 grams of alcohol. What is the specific gravity of alcohol?

9. Let each pupil experimentally determine the specific gravity of some solid that will sink in water.

SECTION IV.

HYDROKINETICS.

171. The Flow of Liquids through Horizontal Pipes.—When liquids from a reservoir are made to flow through pipes of considerable length, the discharge is far less than that due to the head. The diminution is chiefly owing to friction against the sides of the pipe.

The "head" is the *vertical* distance from the centre of the orifice to the surface of the liquid.

172. The Flow of Rivers. — The friction of a stream against its solid bed fortunately retards the velocity of the water. Otherwise the velocity of the current at the mouth of a river, whose head is elevated 1,000 feet above its mouth, would be about 170 miles per hour. Such a current would be disastrous beyond description. The ordinary river current is from three to five miles per hour.

173. Water-power.—Water may be used to turn a wheel and thus move machinery by its weight, the force of the current or both.

174. The Turbine Wheel.—The turbine wheel, of which there are many varieties, is the most effective water-wheel known.

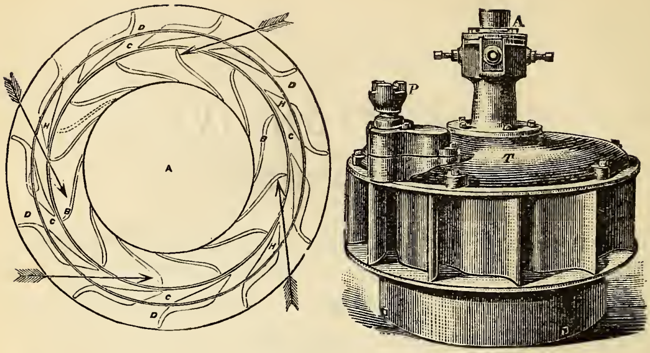

FIG. 54.

(*a.*) Figure 54 represents one form in perspective and in horizontal section through the centre of the wheel and case complete. The wheel, *B*, and the enclosing case, *D*, are placed on the floor of a penstock wholly submerged in water, under the pressure of a considerable head. The water enters, as shown by the arrows, through openings in *D*, which are so constructed that it strikes the buckets of *B* in the direction of greatest efficiency.

(*b.* After leaving the buckets, the "dead water" escapes from the central part of the wheel, sometimes by a vertical draft tube, best made of boiler-iron. The weight of the water in this tube increases the velocity with which the water strikes the buckets.

(*c.*) A central shaft, *A*, is carried by the wheel and communicates its motion to the machinery above. The wheel itself rests upon a central pivot carried by cross-arms from the bottom of the outer case. The case, *D*, is covered with a top, *T*, which protects the wheel from the vertical pressure of the water. The axis of the wheel passes through the centre of this cover.

175. The Overshot Wheel. — In the overshot wheel, the water falls into buckets at the top and, by

its weight aided by the force of the current, turns the wheel. As the buckets are gradually inverted, the water is emptied and the load thus removed from the other side of the wheel.

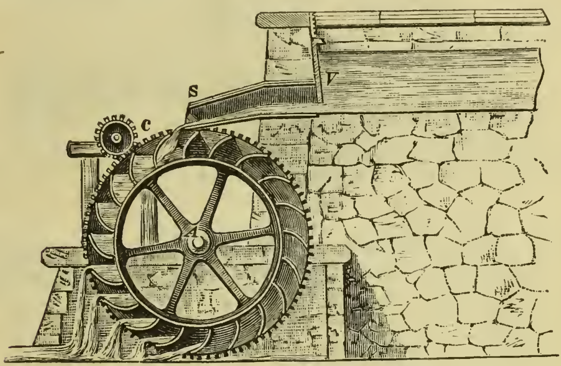

Fig. 55.

Such wheels require not much water but a considerable fall. It is said that they have been made nearly 100 feet in diameter. The water is led to the top of the wheel by a *sluice*, *S V*. The power may be communicated to the machinery by the shaft, *A*, or by the rim of the wheel, as at *c*, according to the desire for intensity of power or for velocity. The water supply may be controlled by a gate at *V*.

176. The Breast Wheel.—In the breast wheel, the water acts upon float boards fixed perpendicular to the circumference. The stream being received at or near the level of the axis, both the weight of the water and the force of the current may be turned to account.

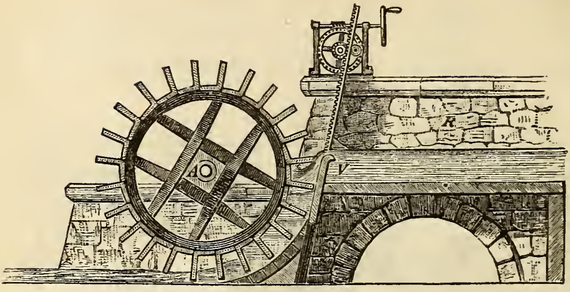

FIG. 56.

177. The Undershot Wheel.—In the undershot wheel, the stream strikes, near the bottom of the wheel, against a few float boards. It is turned by the force of the current.

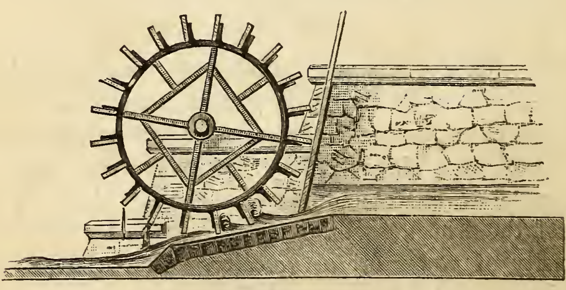

FIG. 57.

NOTE.—In point of efficiency, these wheels rank in the order above given.

REVIEW QUESTIONS.

1. In what direction do liquids at rest exert pressure?

2. Upon what three things does the pressure of a liquid on the bottom of the vessel holding it depend?

3. How may a little water be made to exert a great pressure?

4. Show two ways in which a small weight may be made to balance a heavy one?

5. State two points of difference between solids and liquids?

6. If a pendulum of given length swings through an arc five inches long in one second, how long will it take the same pendulum to swing through an arc of ten inches?

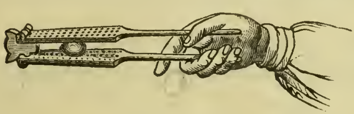

Fig. 58.

7. Show that the apparatus represented in Fig. 58 is a lever, tell of what class it is and indicate the positions for *P*, *W* and *F*.

8. Define malleability.

9. In what direction do fluids transmit pressure with the greatest facility?

10. State the principle that underlies the action of the hydrostatic press?

11. What was Pascal's experiment? Find out who Pascal was.

12. It is stated that the specific gravity of silver is about ten. This means ten *of what?*

13. What is the velocity of an ordinary river current?

14. Describe the hydrostatic bellows. What is meant by the centre of buoyancy?

15. Describe the use of the specific gravity bulb.

16. Experiment shows that it is difficult to balance a lead pencil on the finger. Why is it easier thus to balance it with the additional load of two penknives, as shown in Fig. 59?

Fig. 59.

CHAPTER V.

PNEUMATICS.

SECTION I.

THE ATMOSPHERE AND ATMOSPHERIC PRESSURE.

178. What is Pneumatics?—*Pneumatics is that branch of Physics which treats of aeriform bodies, their mechanical properties and the machines by which they are used.*

179. Tension of Gases.—*However small their quantity, gases always fill the vessels in which they are held.*

If a bladder or India rubber bag, partly filled with air and having the opening well closed, be placed under the receiver of an air-pump (§ 187), the bladder or bag will be fully distended, as shown in the figure, when the air surrounding the bladder is pumped out.

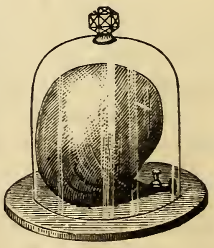

FIG. 60.

The flexible walls are *pushed out* by the air confined within. *This tendency is called elastic force or tension.*

We may imagine the countless molecules of air in the bladder or bag as being in constant motion and continually striking against the walls that confine them. These molecular blows push the walls outward and their total effect constitutes tension.

This conception is generally referred to as the Kinetic Theory of Gases (§ 43, *a*).

180. The Type.—As water was, for obvious reasons, taken as the type of liquids, so *atmospheric air will be taken as the type of aeriform bodies.*

Whatever mechanical properties are shown as belonging to air may be understood as belonging to all gases.

181. Weight of Air.—Being a form of matter, air has weight. This may be shown by experiment. A hollow globe of glass or metal, having a capacity of several quarts or liters and provided with a stop-cock, is carefully weighed on a delicate balance. The air is then removed from the globe by an air-pump, the stop-cock closed and the empty globe weighed carefully. The second weight will be less than the first, the difference between the two being the weight of the air removed.

(*a.*) Under ordinary conditions, a cubic inch of air weighs about 0.31 grains. A liter of air weighs about 1.293 grams, being thus about $\frac{1}{770}$ as heavy as water.

(*b.*) Measure the length, breadth and height of your schoolroom and find the weight of the air that it contains.

Experiment 53.—Fill a tumbler with water, place a slip of thick paper over its mouth and hold it there while the tumbler is inverted: **the water will be supported** when the hand is removed from the card, as is shown in Fig. 61.

FIG. 61.

Experiment 54.—Plunge a small tube, or a tube having a small opening at the lower end, into water, cover the upper end with the finger and lift it from its bath. **The water is kept in the tube by the upward pressure of the atmosphere.** Remove the finger and the downward pressure of the atmosphere, which was previously cut off, will counterbalance the upward pressure and the water will fall by its own weight. Such a tube, called a *pipette,* is much used for transferring small quantities of liquids from one vessel to another.

Experiment 55.—Make a "sucker" of a circular piece of thick leather and fasten a string to its middle. Soak it thoroughly in water and firmly press it upon a flat stone to drive out all air from between the leather and the stone. Pull the string gently so that a vacuum may be formed, as shown in Fig. 62. If the stone be not too heavy, it may be lifted by the string. We shall soon see that, in reality, **the stone is pushed up by the air instead of being pulled up by the string.**

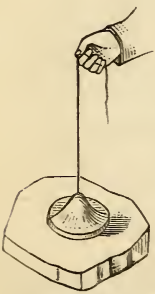

FIG. 62.

Experiment 56.—Suck the air from the hollow stem of a common key and quickly press the open end of the stem against the lip where **it will be held by the pressure of the air.**

Experiment 57.—For a few cents you can buy a four inch test tube of a dealer in chemical glass ware (see *Chemistry,*

Appendix 7). Holding it by the open end, heat the tube quite hot in the flame of a lamp or candle. When the heat has expanded the air and driven part of it out of the tube, press the mouth of the tube against the fleshy part of the hand or thumb **where it will be held by atmospheric pressure.**

Experiment 58. — Vary the last experiment by placing the tube, mouth downward, in a saucer of water. **Atmospheric pressure will force water upward into the tube.**

Experiment 59.—Secure an empty tin fruit can with a hole about two inches in diameter in one end. Smoothly stretch a piece of clean mosquito netting over this end of the can, as shown in Fig. 63. Fill the can with water, place a piece of writing paper over the mosquito netting and hold it there while you invert the can. Draw the paper horizontally from the end of the can. **Atmospheric pressure will prevent the water from running out through the meshes of the mosquito netting.**

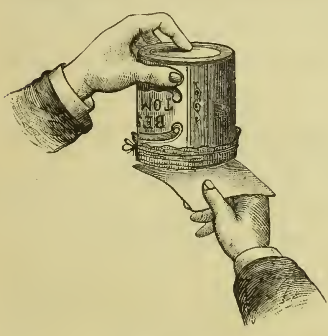

Fig. 63.

Experiment 60.—With a small nail, punch a hole in the middle of the closed end of the can used in the last experiment. Repeat that experiment, keeping the nail-hole covered by the forefinger, as shown in Fig. 63. Remove the finger for an instant, quickly covering the hole again. When the atmosphere has a chance to press downward through the nail-hole upon the water in the can, the water runs out through the mosquito netting. When this opportunity is removed by closing the nail-hole, **the water is held in the can by the upward pressure of the atmosphere.**

182. Atmospheric Pressure. — The atmosphere exerts a great pressure upon the surface of the earth and all bodies found there. This atmospheric pressure decreases as we ascend from the earth's surface.

The weight of a column of air one inch square and extending from the sea-level to the upper limit of the atmosphere is about fifteen pounds; a similar column, a centimeter square, weighs about one kilogram.

We express this by saying that the atmospheric pressure at the sea-level is fifteen pounds to the square inch, or one kilogram to the square centimeter.

(*a.*) Several illustrations of atmospheric pressure will be given after we have considered the air-pump.

183. Torricelli's Experiment. — The intensity of atmospheric pressure may be measured as follows:

Take a glass tube a yard long, about a quarter of an inch in internal diameter. Close one end and fill the tube with mercury. Cover the other end with the thumb or finger and invert the tube, placing the open end in a bath of mercury. Upon removing the thumb, the mercury will sink and come to rest at a height of about 30 inches, or 760 millimeters, above the level of the mercury in the bath.

The apparatus used, when properly graduated, becomes a *barometer*.

184. Pascal's Experiments.—Pascal repeated Torricelli's experiment on the top of a mountain and found that the mercury column was three inches shorter, show-

ing that as the weight of the atmospheric column diminishes, the supported column of mercury also diminishes.

He then took a tube forty feet long, closed at one end. Having filled it with water, he inverted it over a water bath. The water in the tube came to rest at a height of 34 feet. The water column was 13.6 times as high as the mercury column, but as the specific gravity of mercury is 13.6, the weights of the two columns were equal.

Experiments with still other liquids gave corresponding results, all of which strengthened the theory that the supporting force is due to the weight of the atmosphere and left no doubt as to its correctness.

185. Pressure Measured in Atmospheres.—A gas or liquid which exerts a force of 15 pounds upon a square inch or one kilogram upon a square centimeter of the restraining surface is said to exert a pressure of one atmosphere. A pressure of 60 pounds to the square inch, or 4 kilograms to the square centimeter would be called a pressure of 4 atmospheres.

186. Recapitulation.—To be amplified by the pupil for review.

PNEUMATICS.
- DEFINITION.
- TENSION.
- TYPE IS AIR.
  - PRESSURE.
    - *Per square inch.*
    - *Per square centimeter.*
    - *Measured in atmospheres.*
    - *Torricelli.*
    - *Pascal.*
  - WEIGHT..

EXERCISES.

1. The downward pressure of the atmosphere on the bottom of an ordinary wooden pail is about a ton. Why is not the bottom forced out and how can any person carry the pail?

2. Suppose a bottle to be tightly corked at the top of a high mountain, carried to the sea-level and opened with its mouth under water. Would air bubble out or water rush in?

3. What is the pressure on one side of a window 2 feet by 6 feet? *Ans.* 25920 lb.

4. What is the pressure on one side of a door 1 meter by 2 meters?

5. Why is a barometer tube closed at the top?

6. Why is a barometer tube not closed at the bottom?

7. When the barometer stands at 28 inches, at what height would the water in the tube of Pascal's experiment come to rest?

8. A steam-boiler was tested "at a pressure of 10 atmospheres." What does this mean?

SECTION II.

AIR-PUMPS.—LIFTING AND FORCE-PUMPS.—SIPHON.

187. The Air-Pump.—*The air-pump is an instrument for removing air from a closed vessel.*

The essential parts are shown in section by Fig. 64.

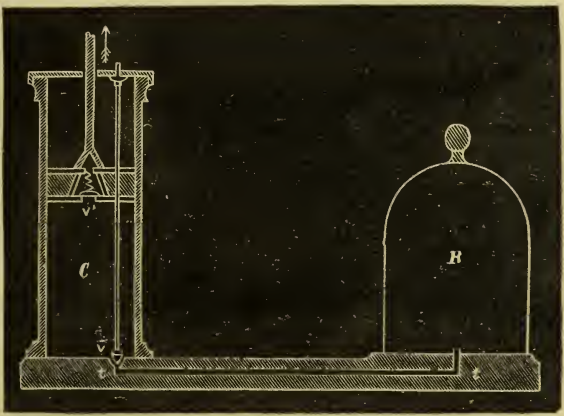

Fig. 64.

The vessel, R, is called a receiver. It fits accurately upon a horizontal plate, through the centre of which is an opening communicating with a cylinder, C, by means of a bent tube, t. An accurately fitting piston moves in the cylinder. At the junction of the bent tube with the cylinder and in the piston, are two valves, v and v',

opening from the receiver but not toward it. When the piston is raised, v' closes and the atmospheric pressure is removed from v. The tension of the air in R opens v. The air which was in R and t expands and fills R, t and C. When the piston is pushed down, v closes, v' opens and the air in C escapes from the apparatus.

NOTE.—A person having an air-pump has the means of performing almost numberless experiments, some amusing and all instructive. A cheap and efficient air-pump may be bought of JAMES W. QUEEN & Co., Philadelphia. Several experiments with the air-pump are given below. Others will be found in *The Elements of Natural Philosophy.*

Experiment 61.—The *hand-glass* is a receiver open at both ends. See that the lower end fits accurately upon the plate of the air-pump. (It is well to smear the plate with tallow in this and similar experiments.) Place the hand over the other end. When the pump is worked, the pressure of the atmosphere is felt, and the hand can be removed only by a considerable effort. **The appearance of the palm of the hand at the end of this experiment is due to the tension of the air within the tissues of the hand.**

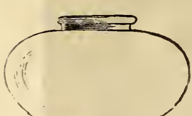

FIG. 65.

Experiment 62.—Perform the experiment described in § 179.

Experiment 63.—Over the upper end of a cylindrical receiver, tie tightly a wet bladder and allow it to dry. Then exhaust the air. **The bladder will be forced inward, bursting with a loud noise.** It may be necessary to prick a

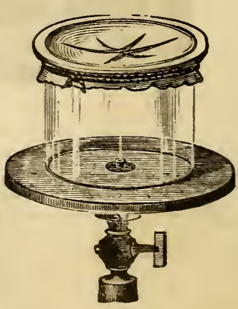

FIG. 66.

pin-hole through the bladder after the receiver has been exhausted.

Experiment 64.—Replace the bladder with a piece of thin india-rubber cloth. Exhaust the air. The cloth will be forced inward by atmospheric pressure and nearly cover the inner surface of the receiver.

NOTE.—The hand-glass, used in Experiment 61, will answer for the two experiments last given, by placing the small end upon the pump-plate.

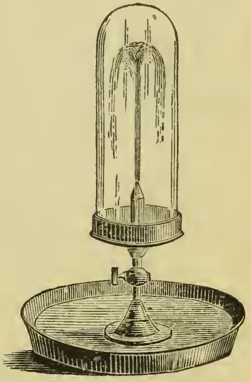

FIG. 67.

Experiment 65.—The *"fountain in vacuo"* consists of a glass vessel, through the base of which passes a tube terminating in a jet within, and provided with a stop-cock and screw without. By means of the screw, it may be attached to the air-pump. Remove the air, close the stop-cock, place the lower end of the tube in water, open the stop-stock ; a beautiful fountain will be produced (Fig. 67).

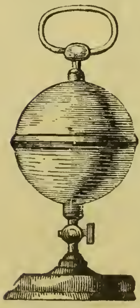

FIG. 68.

Experiment 66.—The *Magdeburg hemispheres* are made of metal (Fig. 68). They are hollow and generally three or four inches in diameter. The edges being greased and placed together, the air is exhausted from the hollow globe through a tube provided with a stop-cock and screw. When the air has been pumped out, close the stop-cock and remove the hemispheres from the pump. It will be found that a considerable force is necessary to pull the hemispheres asunder. **This force is equal to the atmospheric pressure upon the circular area inclosed by the edges of the hemispheres.** If

this area be ten square inches, it will require a pull of 150 pounds to separate the hemispheres.

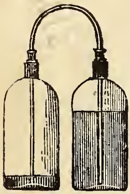

FIG. 69.

Experiment 67.—Partly fill two bottles with water. Connect them by a bent tube which fits closely into the mouth of one and loosely into the mouth of the other. Place the bottles under the receiver and exhaust the air. Water will be driven from the closely stoppered bottle into the other. Readmit air to the receiver and the water thus driven over will be forced back.

188. The Condenser.—*The condenser is an instrument for compressing a large amount of gas into a closed vessel. The chief difference between it and the air-pump is that its valves open toward the receiver.*

189. The Lifting-pump.—The lifting-pump consists of a cylinder or barrel, *c*, a piston, *p*, two valves, *v v*, and a suction pipe, *s*, the lower end of which dips below the surface of the liquid to be raised. The arrangement is essentially the same as in the air-pump.

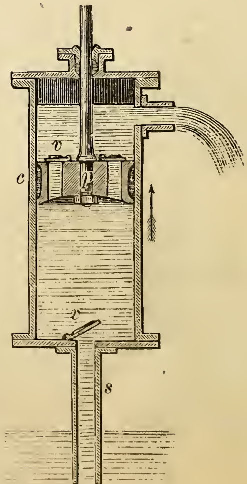

FIG. 70.

As the piston is worked, the air below it is gradually removed. The downward pressure on the liquid in the pipe being thus removed, *the pressure of the atmosphere, exerted upon the*

surface of the liquid, pushes the liquid up through the suction pipe and the lower valve into the barrel.

When the piston is again pressed down, the lower valve closes, the reaction of the water opens the piston valve and the piston sinks below the surface of the liquid in the barrel. When next the piston is raised, it lifts the water above it toward the spout of the pump. At the same time, atmospheric pressure forces more liquid through the suction pipe into the barrel.

190. Practical Points.—The cistern or well containing the liquid must not be cut off from atmospheric pressure, *i. e.*, must not be made air-tight. For water pumps, the suction pipe must not be more than 34 feet high. Owing to mechanical imperfections chiefly, *the practical limit of the water pump is about 28 vertical feet.*

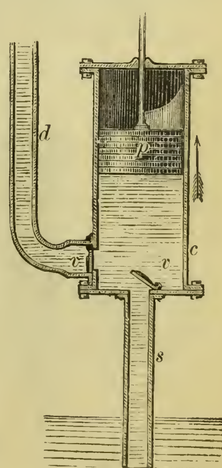

FIG. 71.

191. The Force-Pump.—In the force-pump, the piston is often made solid, *i. e.*, without any valve. The upper valve is placed in a discharge pipe, *d*, which opens from the barrel at or near its bottom.

When the piston is raised, water is forced into the barrel by atmospheric pressure. When the piston is forced down, the suction pipe valve is closed, the water being forced

through the other valve into the discharge pipe. When the piston is raised again, the discharge pipe valve is closed, preventing the return of the water above it, while atmospheric pressure forces more water from below into the barrel.

Sometimes the upper valve is placed in the piston, as in the ordinary lifting-pump, the discharge pipe opening from the upper part of the cylinder which is closed at the top.

192. Direction of Valve Openings.—In the case of the air-pump, the condenser, the lifting and force-pumps, *the valves open in the direction in which the fluid is to move.*

193. The Air-Chamber of a Force-Pump.—Water will be thrown in spurts from a pump like that represented in Fig. 71. *A continuous flow is secured by connecting the discharge pipe with an air-chamber.*

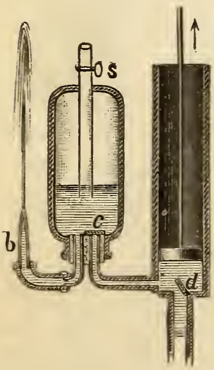

Fig. 72.

This air-chamber, *c*, is provided with a delivery pipe, *b* or *s*, which reaches below the surface of the water in the air-chamber.

When water is forced into the air-chamber, it covers the mouth of the delivery pipe and compresses the air confined in the chamber. This lessening of the volume of the air causes an increased ten-

sion (§ 179), which soon becomes sufficient to force the water through the delivery pipe in a continuous stream.

A pump may have both delivery pipes but one of them must be closed by a cock, as shown at *s*.

Experiment 68.—Set a pail of water on the table. Place one end of a piece of rubber tubing in the water and let the other end hang over the edge of the pail reaching below the top of the table. Suck some water through the tube. Water will continue to flow until the pail is emptied or the water surface falls below the end of the tube in the pail.

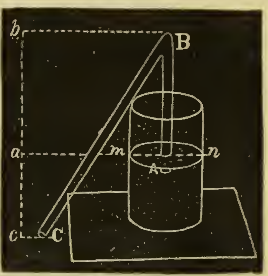

FIG. 73.

194. The Siphon. — *The siphon consists of a bent tube, open at both ends, having one arm longer than the other.*

It is used to transfer liquids from a higher to a lower level, especially in cases where they are to be removed without disturbing any sediment they may contain.

The siphon may be first filled with the liquid and then placed with the shorter arm in the vessel, care being had that the liquid does not escape from the tube until the opening, *C*, is lower than *m n*, the surface of the liquid; or it may be first placed in position and the air removed by suction at the lower end.

The pressure of the atmosphere will force the liquid up the shorter arm and fill the tube. In either case, a constant stream of the liquid will flow from the vessel

until the surface line, *m n*, is brought as low as the opening in the shorter arm or, if the liquid be received in another vessel, until the level is the same in the two vessels.

(*a.*) The action of the siphon is explained in the author's larger work. If the liquid to be transferred is water, the height, *a b*, must be less than thirty-four feet.

195. Recapitulation.—To be amplified by the pupil for review.

- **PUMPS...**
  - AIR...........
    - DEFINITION.
    - CONSTRUCTION.
    - LIMITATIONS.
    - EXPERIMENTS.
  - CONDENSER.
  - WATER.......
    - LIFTING.
    - FORCE.
  - *Valve Openings.*

THE SIPHON.

EXERCISES.

1. What is the total atmospheric pressure (in pounds) upon the surface of a wooden cube one inch on each edge?

2. If mercury is 13.6 times as heavy as water, and a given pump will lift water to the height of 28 feet, how high will the same pump, *other conditions being similar*, lift the mercury?

3. How can you arrange a single suction or lifting-pump to raise water from the bottom of a well 50 feet deep?

4. Construct the apparatus shown in Fig. 74, filling each of the three bottles half full of water. Blow in the tube, *f*, until a jet is formed at *n*. Explain the continued action of the apparatus.

Be sure that all joints made by the corks of the three bottles are air-tight. For directions in working glass tubing, see *Chemistry*, Appendix 4.

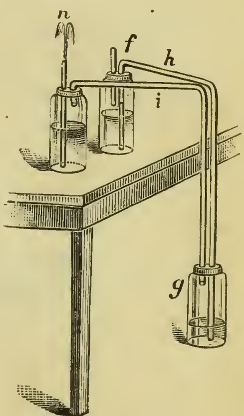

FIG. 74.

5. How many valves are there in a force-pump? Where are they placed and in what direction do they open?

6. What is the thing sometimes erroneously called "the force of suction"?

7. The volume of a given quantity of a gas or vapor will be inversely proportional to the pressure exerted upon it. A cubic foot of steam (measured under a pressure of one atmosphere) will have what volume under a pressure of 8 atmospheres?

Ans. 216 cubic inches.

REVIEW QUESTIONS.

1. (*a.*) When an inverted bottle is held under water, why does not the water fill it? (*b.*) Why is it that *any* water enters the bottle?

2. (*a.*) When the sails of a ship are taken down, why does not the boat suddenly stop? (*b.*) What finally stops the ship?

3. Why does not a stone move in a straight line when thrown horizontally?

4. What is the difference between the words "vertical" and perpendicular"?

5. When a bullet is flattened by the target, what "law" is thereby illustrated?

6. Why does a freely falling body increase in velocity?

7. What has become of the energy expended centuries ago in building the still remaining parts of the Egyptian pyramids?

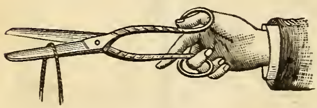

FIG. 75.

8. What kind of a lever is represented in Fig. 75? Indicate the positions for P, W and F.

9. What is always the dividend in problems in specific gravity?

10. If a pendulum, having a certain length and a weight of 2 ounces, vibrates once a second, how often will a pendulum having the same length and a weight of 6 ounces vibrate?

11. State the law of weight.

12. State, in ordinary language, the meaning of the formula, $s = \frac{1}{2} gt^2$.

13. What is the difference between Kinetic and Potential Energy?

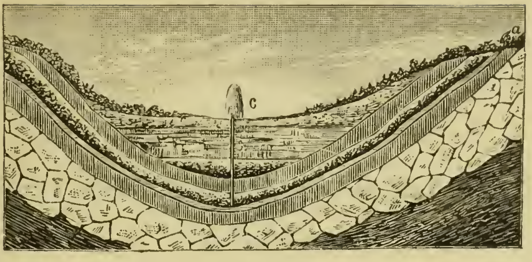

FIG. 76.

14. A stratum of sand or gravel through which water can easily work its way, comes to the surface of the ground at *a*, Fig. 76. This stratum is inclosed between two curved strata impervious to water. When a hole is bored at *c* until it strikes the stratum, *a*, an artesian well is formed. Explain the action of the artesian well.

CHAPTER VI.

ELECTRICITY AND MAGNETISM.

SECTION I.

GENERAL VIEW.

196. Importance of the Subject. — We are now to begin the study of a class of phenomena of intense interest and almost unlimited practical importance. Every pupil has seen the lightning flashing in the stormy sky and wondered at the cause of the terrible, yet beautiful, display. Later in life, he was told that lightning is electricity. He has seen or heard of trees and houses shattered by the lightning stroke and may now remember that *if electricity can do this work, it must be a form of energy.*

He is told that the telegraph is electricity under control and working at the will of man. When he reads the daily paper and learns of events that took place only a few hours before in Europe, Asia or Africa as well as in every part of his own country, he must, it seems, think of the wondrous speed of this form of energy as it courses under the waters of the sea and over the valleys, plains and mountains of the land. With the aid of the

telephone, he talks with friends and recognizes their voices though they be miles away. He is a fit subject for pity if he has no desire to know how these things are done.

He hears of the mysterious power that points the needle of the mariner's compass to the north and guides the ship across the trackless waters. He is told that this power is called magnetism, that it is closely associated with electricity and is frequently produced by it. He sees the electric light and is surprised to find that, in turn, magnetism produces electricity. He talks with the merchant or manufacturer about these and other things, that were lately wonders and conveniences but have now become common-place necessities of business life, and finds that the so-called "practical" man of the world is forced to acknowledge his great and ever increasing obligation to modern science. He probably gets the idea that *it will pay* for him to learn more about these things.

197. Simple Apparatus.—Provide two stout sticks of sealing-wax and one or two pieces of flannel folded into pads about 20 centimeters (8 inches) square; two glass rods or stout tubes closed at one end, 30 or 40 centimeters in length and about 2 centimeters in diameter (long "ignition tubes" will answer) and one or two silk pads about 20 centimeters square, the pads being three or four layers thick; a few pith balls about 1 centimeter in diameter (whittle them nearly round and finish by rolling them between the palms of the hands); a silk ribbon

FIG. 77.

about an inch wide and a foot long; a balanced straw about a foot long, represented in Fig. 77. The ends of the straw carry two small discs of paper (bright colors preferable) fastened on by sealing-wax. The cap at the middle of the straw is a short piece of straw fastened by sealing-wax. This is supported upon the point of a sewing-needle, the other end of which is stuck upright into the cork of a small glass vial. From the ceiling or other convenient support, suspend one of the pith balls by a fine silk thread.

(*a.*) The efficiency of the silk pad above mentioned may be increased by smearing one side with lard and applying an amalgam, made of one weight of tin, two of zinc and six of mercury. The amalgam which may be scraped from bits of a broken looking-glass answers the purpose admirably. A piece of cat-skin or other fur may be used instead of the flannel pads. See that the sealing-wax and glass rods, the flannel and silk pads are perfectly dry. Have them quite warm, that they may not condense moisture from the atmosphere.

Experiment 69.—Draw the silk ribbon between two layers of the warm flannel pad with considerable friction. Hold it near the wall of the room. **The ribbon will be drawn to the wall and held there for some time.**

Place a sheet of paper on a warm board and briskly rub it with india-rubber. Hold it near the wall as you did the ribbon.

Experiment 70.—Briskly rub the sealing-wax with the flannel and bring the wax near the suspended pith ball. The ball will be drawn to the wax. Bring the wax near one end of the balanced straw; it may be made to follow the wax round and round. Bring it near small scraps of paper, shreds of cotton and silk, feathers and gold leaf, bran and sawdust, and other light bodies; **they are attracted to the wax.** (Fig. 78.)

Experiment 71.—Repeat all of these experiments with a glass rod which has been rubbed with the silk pad.

Experiment 72.—Make a light paper hoop or an empty egg-shell roll after your rod.

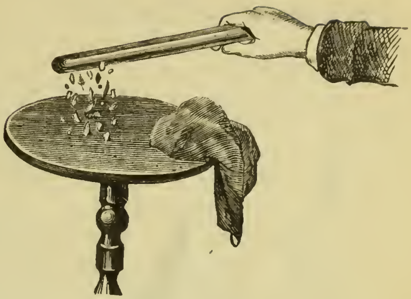

FIG. 78.

Experiment 73.—Place an egg in a wine-glass or an egg-cup. Upon the egg balance a yard-stick or a common lath. The end of the stick may be made to follow the rubbed rod round and round. Place the blackboard pointer or other stick in a wire loop or stiff paper stirrup suspended by a stout silk thread or narrow silk ribbon. It may be made to imitate the actions of the balanced straw or lath.

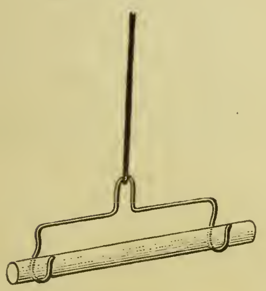

FIG. 79.

Experiment 74.—Suspend the rubbed sealing-wax or glass rod as you did the blackboard pointer in the last experiment. Hold your hand near the end of the rod. **It will turn round and approach your hand.**

NOTE.—The pupil may be ingenious enough to *invent new experiments* for himself and the class. The ability to invent is often very valuable and may be acquired early in life. Most of the great inventors began making experiments when mere children.

198. Electric Attraction.—*The attractions manifested in these experiments were due to electricity that was developed by friction.*

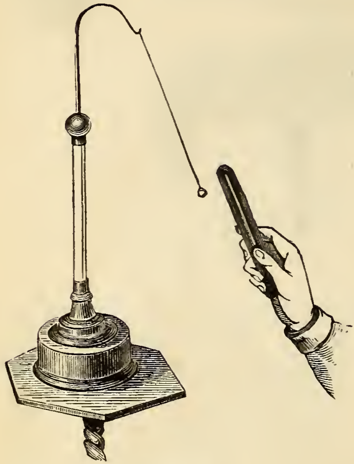

Fig. 80.

Experiment 75.—Bring the rubbed sealing-wax or glass rod near the pith ball again. It will attract the ball as in Experiment 70. Allow the ball to touch the rod and notice that in a moment the ball is thrown off. If the ball be pursued with the rod, it will be found that **the rod which attracted it a moment ago, now repels it.** Evidently the ball has acquired a new property.

Experiment 76.—Touch the ball with the finger. It seeks the rubbed rod, touches the rod, flies from the rod. Repeat the experiments with the sealing-wax after it has been rubbed with flannel.

Experiment 77.—Rub the glass rod with silk and bring it over the small scraps of paper, as in Experiment 71. Notice that after the attraction the paper bits do not merely fall down, **they are thrown down.**

199. Electric Repulsion.—*The repulsions manifested in these experiments were due to electricity that was developed by friction. Such*

electricity is called frictional or static electricity.

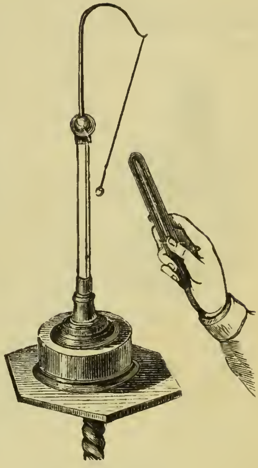

FIG. 81.

The glass or wax is said to be *electrified by friction.* The ball, after obtaining its new property of repulsion by coming into contact with the glass or wax is said to be *electrified by conduction.* The suspended pith ball is called an *electric pendulum.*

Experiment 78.—Prepare a battery solution according to the recipe given in § 258, *b*, using only half the quantity of each substance as therein directed. While the solution is cooling, provide a piece of sheet copper and one of sheet zinc, each about 10 centimeters (4 inches) long and 4 centimeters ($1\frac{1}{2}$ inches) wide. To one end of each strip, solder (see Appendix) or otherwise fasten a piece of copper wire about 15 centimeters (6 inches) long and 1 millimeter ($\frac{1}{16}$ to $\frac{1}{32}$ inch) thick. Place the zinc strip in a common tumbler about three-fourths full of the battery solution. Notice the minute bubbles that break away from the surface of the zinc and rise to the surface of the liquid. These are bubbles of hydrogen, a combustible gas. **The formation of the gas is due to chemical action between the zinc and the liquid.**

Experiment 79.—Take the zinc from the tumbler and, while it is yet wet, rub a few drops of mercury (quicksilver) over its surface until it has a brilliant, silver-like appearance. Replace the zinc, thus amalgamated, in the solution and notice that **no bubbles are given off.**

Experiment 80.—Place the copper strip in the liquid, taking care that it or its wire does not touch the zinc or its wire. **No bubbles appear on either the zinc or the copper.** It may be convenient to place a narrow glass strip between the ends of the metal strips in the tumbler to keep them apart.

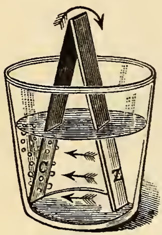

FIG. 82.

Experiment 81.—Bring the upper ends of the strips together, as shown in Fig. 82, or, still better, join the two wires, as shown in Fig. 102, being sure that the wires are clean and bright where they are united. **Notice the formation of bubbles on the surface of the copper, where none previously appeared.**

200. Suspicion.—It certainly seems that the connecting wire is an important part of the apparatus as now arranged and we are led to suspect that something unusual is taking place in the wire itself. It is evident that we have a complete "circuit" through the liquid, the metal strip and the wire.

Experiment 82.—Untwist the wires or, in other words, "break the circuit." Connect the copper wires with a short piece of *very fine* iron wire. The connections should be made so that the circuit shall include about 2 centimeters ($\frac{3}{4}$ inch) of iron wire. **The iron will become hot** enough to burn the fingers or to ignite a small quantity of gun cotton twisted around it.

Experiment 83.—If one of the copper wires be twisted around one end of a small file and the other wire be drawn along its rough surface, **a series of minute sparks will be produced** as the circuit is rapidly made and broken.

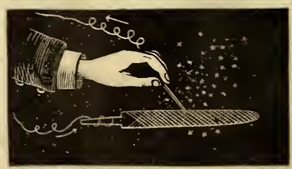
FIG. 83.

Experiment 84.—Place the cell so that the joined wires shall run north and south, passing directly over the needle of a small compass (§ 295, *b.*) and near to it. **The needle will instantly turn** as though it were trying to place itself at right angles to the wire. Break the circuit and the needle will swing back to its north and south position.

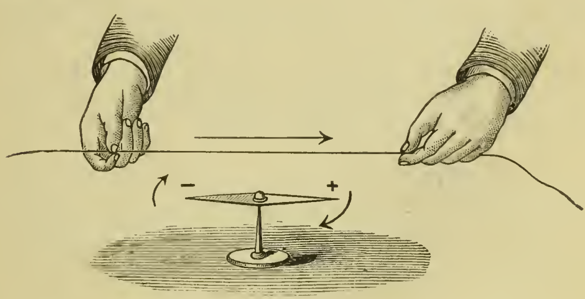

FIG. 84.

201. Certainty.—We now feel sure that something unusual is taking place in the wire of our complete circuit for we have seen the wire become hot, explode guncotton, yield sparks and exert a very mysterious influence upon the magnetic needle. As a matter of fact, we now have a current of electricity flowing through a galvanic cell.

Electricity thus produced by chemical action is called galvanic or voltaic electricity. It is one form of current electricity.

Experiment 85. — Wrap a piece of writing paper around a large iron nail leaving the ends of the nail bare. Wind fifteen or twenty turns of stout copper wire around this paper wrapper, taking care that the coils of the wire spiral do not touch each other or the iron, It is well to use cotton covered or "insulated"

wire. Connect the two ends of the wire spiral with the two wires of the galvanic cell or, in other words, put the spiral into the circuit. Dip the end of the nail into iron filings. **Some of the filings will cling to the nail in a remarkable manner.** Upon breaking the circuit, the nail instantly loses its newly acquired power and drops the iron filings.

If the experiment does not work satisfactorily, look carefully to all the connections of the circuit, see that the ends of the wires are clean and bright and that they are twisted together firmly. It may even be necessary to wash the plates, rub more mercury on the zinc and provide a fresh battery solution.

202. Temporary Magnets. — You have probably satisfied yourself that the nail has the power of attracting iron filings *while the electric current is flowing through the wire.*

You have made an electro-magnet and its power of attracting iron is called magnetism.

Satisfy yourself, by trial, that the nail loses its magnetism as soon as the circuit is broken or the current ceases to flow around it and remember that your electromagnet is a *temporary magnet.*

Experiment 86. —While the nail is magnetized, draw a sewing-needle four or five times from eye to point across one end of the electro-magnet. Dip the needle into iron filings; **some of them will cling to each end of it.**

203. Permanent Magnets.—When steel is treated as in the last experiment, it becomes permanently magnetized.

Experiment 87.—Cut a thin slice from the end of a vial cork and, with its aid, float your magnetized needle upon the surface of

a bowl or saucer of water. **The needle comes to rest in a north and south position.** Turn it from its chosen position and notice that after each displacement it resumes the same position and that **the same end of the needle always points to the north.**

204. A Simple Compass.—*A small magnetized steel bar freely suspended, is called a compass.*

The one that you have made may be less convenient but is as reliable as the compass of the mariner or the surveyor.

205. Artificial Magnets.—The electro-magnet and the permanent magnet that you made are, of course, *artificial magnets.* There is a *natural magnet* known as lodestone.

206. Other Forms of Current Electricity.—Electric currents may be generated by the action of other currents of electricity or by the action of magnets. Electricity thus developed is called *induced electricity.*

A current of electricity that is generated by heating the junction of two metals that form part or all of a circuit is called *thermo-electricity.*

207. The Different Forms of Electricity are Identical.—So far as experiment can show, one form of electricity may have a particular property in greater degree than some other form but all are identical, each having all the properties of any of the others.

208. Recapitulation.—To be amplified by the pupil for review.

- **ELECTRICITY.**
  - IMPORTANCE OF THE SUBJECT.
  - Produced by
    - FRICTION, MANIFESTING ...
      - ATTRACTION..................
      - REPULSION....................
    - CHEMICAL ACTION.
      - LIQUID.
      - PLATES.
      - WIRE.
        - CURRENT PRODUCES MAGNETS.
          - TEMPORARY.... ...
          - PERMANENT ....
          - COMPASS NEEDLES.

All Forms of Electricity are Identical in Nature.

SECTION II.

FRICTIONAL ELECTRICITY OR ELECTRIC CHARGES.

209. The Nature of Electricity. — But little is known concerning the real nature of electricity. It is easier to tell what electricity can do than to tell what it is.

The majority of modern physicists consider that *electricity is a form of energy producing peculiar phenomena; that it may be converted into other forms of energy and that all other forms of energy may be converted into it.*

Several theories have been advanced to account for electrical phenomena but none of them is satisfactory.

210. Electric Manifestations.—*Electricity may reveal itself as a charge or as a current.*

By means of friction, the glass rod or the sealing wax (§§ 198, 199) acquired an electrical charge and, consequently, the power of attracting and repelling light bodies: by means of chemical action, the galvanic cell generated electricity that manifested itself as a current. *In this section, we shall consider electricity that appears as a charge, i. e., static electricity.*

Experiment 88.—Prepare two electric pendulums. Bring the electrified glass rod near the pith ball of one; after contact, the

ball will be repelled by the glass. Bring the electrified sealing-wax near the second pith ball; after contact it will be repelled by the wax. Satisfy yourself that the electrified glass will repel the first; that the electrified sealing-wax will repel the second. Let the glass rod and the sealing-wax change hands. The first ball was repelled by the glass; it will be **attracted by the sealing-wax.** The second ball was repelled by the sealing-wax; it will be **attracted by the glass.**

Experiment 89.—Suspend two pith balls, as shown in Fig 85, and touch them with a rubbed glass rod. Instead of continuing to hang side by side, they repel each other and fly apart. If the electrified glass rod be held near them, they separate still further. If the electrified sealing-wax, instead of the glass, be held near them they will fall nearer together. If the rubbed glass rod be suspended, as shown in Fig. 79, it will be repelled by another rubbed glass rod but attracted by rubbed sealing-wax.

FIG. 85.

211. Two Kinds of Electricity.—*The electricity developed on glass is different in kind from that developed on sealing-wax.*

They exhibit opposite forces to a third electrified body, *each attracting what the other repels.* The self-repulsion of *the parts* of an electrified body may be beautifully illustrated by electrifying a soap-bubble which will thus be made to expand.

212. Only Two Kinds of Electricity.—*All electrified bodies act like either the glass or the sealing-wax.*

213. The Two Electricities Named.—*The electricity developed on glass by rubbing it with silk is called positive or +.*

The electricity developed on sealing-wax by rubbing it with flannel is called negative or —.

The terms *vitreous* and *resinous* respectively were formerly used.

214. The Law of Electrostatics.—The most important electrostatic law may be stated thus :

Electric charges of like signs repel each other; electric charges of opposite signs attract each other.

215. Electroscopes.—*An instrument used to detect the presence of electricity, or to determine its kind, is called an electroscope.*

The electric pendulum (§ 199) is a common form of the electroscope. Two strips of the thinnest tissue paper hanging side by side constitute a simple electroscope. It is well to prepare the paper beforehand by soaking in a strong solution of salt in water and drying.

The balanced straw (Fig. 77) or, better yet, two gilt pith balls connected by a light needle of glass or sealing-wax balanced horizontally on a vertical pivot or a goose-quill balanced on the point of a sewing-needle, makes a convenient electroscope.

The gold leaf electroscope is represented in Fig. 86. A metallic rod, which passes through the cork of a glass vessel, terminates below in two narrow strips of gold leaf and above in a metallic knob or plate. The object of the vessel is to protect the leaves from disturbance by air currents. The upper part of the glass is often coated with a solution of sealing-wax or shellac in alcohol, to lessen the deposition of moisture from the atmosphere. This instrument may be made by the pupil and, when well made, is very delicate.

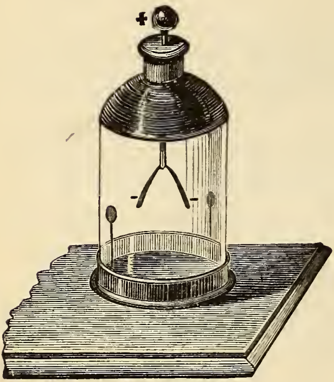

FIG. 86

Experiment 90. — From a horizontal glass rod or tightly-stretched silk cord, suspend a fine copper wire, a linen thread and two silk threads, each at least a yard long. To the lower end of each, attach a metal weight of any kind. Place the weight supported by the wire upon the plate of the gold leaf electroscope. Bring the electrified glass rod near the upper end of the wire; the gold leaves *instantly* diverge. Repeat the experiment with the linen thread: *in a little while* the leaves diverge. Repeat the experiment with the dry silk thread; the leaves do not diverge *at all.* Rub the rod upon the upper end of the silk thread; no divergence *yet appears.* Wet the second silk cord thoroughly and, with it, repeat the experiment; the leaves then diverge *instantly.*

216. Conductors.—Such experiments clearly show that *some substances transmit electricity readily and that others do not.*

Those that offer little resistance to the passage of electricity are called conductors; those that offer great resistance are called non-conductors or insulators.

A conductor supported by a non-conductor is said to be insulated.

(*a.*) In the following table, the substances named are arranged in the order of their conductivity:

Conductors.	5. Salt water.	10. Cotton.	15. Porcelain.
1. Metals.	6. Fresh water.	11. Dry wood.	16. Glass.
2. Charcoal.	7. Vegetables.	12. Paper.	17. Sealing-wax.
3. Graphite.	8. Animals.	13. Silk.	18. Vulcanite.
4. Acids.	9. Linen.	14. India rubber.	*Insulators.*

The fact that a conductor in the air may be insulated, shows that air is a non-conductor. Dry air is a very good insulator, but moist air is a fairly good conductor for electricity of high potential. **All experiments in frictional electricity should, therefore, be performed in clear, cold weather** when the atmosphere is dry, for a moist atmosphere renders insulation for a considerable length of time impossible.

Experiment 91.—Support a yard-stick or common lath upon a glass tumbler. Bring the glass rod, electrified by rubbing it with silk, to one end of the stick and hold some small pieces of paper under the other end of the stick. The paper will be attracted and repelled by the stick as they previously were by the glass itself. **The electricity passed along the stick from end to en**

217. Tension.—Electricity exists under widely different conditions with respect to its ability to force its way through a poor conductor or to leap across a gap.

The electricity developed in a galvanic cell will not pass through even a very thin piece of dry wood; the electricity developed by rubbing the glass rod will pass through several feet of dry wood.

It would require a battery of many cells to force a current across a gap of $\frac{1}{1000}$ of an inch. It is not difficult to force frictional electricity across a gap of several inches while we all know that, in the case of lightning, electricity leaps across a gap of many hundred feet.

In the one case, the electricity is said to be of low potential; in the other case, it is said to be of high potential. We are now dealing with electricity of high potential.

The terms, "low tension" and "high tension" are often used in the same sense.

218. Potential. — The term electrical potential (or simply potential) has reference to the electrical condition of a body or to its degree of electrification. If the potential of *A* be higher than that of *B*, and the two bodies be connected by a good conductor, *an electric current will flow from A to B until the potentials are alike.*

Difference of potential is somewhat analogous to difference of liquid level and gives rise to electromotive force.

219. Electromotive Force. — Electromotive force (often written *E. M. F.*) is the mysterious power which causes electricity to move from one point to another. It is somewhat analogous to hydrostatic pressure. Wher-

ever there is difference of potential, there is *E. M. F.*, but the terms are not synonymous.

The unit of electromotive force is called a volt.

A volt is a little less than the *E. M. F.* of a Daniell cell (§ 260).

220. Resistance.—Every electric circuit offers a resistance to the passage of the current. This resistance will, of course, depend largely upon the conductivity of the material used for the circuit.

With a given material for the conductor, the resistance varies directly as the length and inversely as the weight of a given length.

If one conductor is twice as long as another made of the same kind of wire, the resistance of the longer will be twice as great as that of the shorter.

If one conductor be twice the diameter of another made of the same length and material, the weight *per* foot or yard will be ($2^2 =$) four times as great and the resistance of the first will be one-fourth as great as that of the second.

If they be made of the same material and length, one weighing twice as much *per* foot as the latter, the resistance of the former will be half as great as that of the latter.

The unit of resistance is called an ohm.

A galvanized iron (telegraph) wire, 4 millimeters in diameter and 100 meters long, or a pure copper wire, 1 millimeter in diameter and 48 meters long, has a resistance of about one ohm.

A megohm is a million ohms.

221. Charging by Contact.—If an insulated, unelectrified conductor be brought into contact with a similar conductor that is electrified, or near enough to it for the passage of an electric spark, electricity will pass from the latter to the former until the two conductors are equally charged with the same kind of electricity. *The former is said to be charged by conduction.*

222. Induction.—Actual contact with an electrified body is not necessary for the manifestation of electric action in an unelectrified body. When an electrified body, *C*, is brought near an insulated unelectrified conductor, *B*, provided with electric pendulums, as shown in the figure, the latter shows electric action. The electricity of *C* repels one kind of electricity in *B* and attracts the other, thus separating them. The second body, *B*, is then said to be *polarized.*

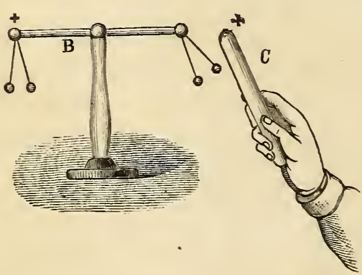

Fig. 87.

The two kinds of electricity in *B*, each of which a moment ago rendered the other powerless, are still there but they have been separated and each clothed with its proper power. This effect is due to the action of the electrified body, *C*, which is said to produce electric

separation by *induction.* When C is removed, the separated electricities of B again mingle and neutralize each other.

(*a.*) Conductors for the purposes of this and similar experiments may be made of wood covered with tin-foil, gold leaf or Dutch leaf. They may be insulated by fastening them on top of long necked bottles or sticks of sealing-wax or by suspending them by silk threads.

(*b.*) Prick a pin hole in each end of a hen's egg and blow out the white and the yolk. Paste tin-foil smoothly over the whole surface of the egg. Fasten one end of a white silk thread to the egg with a drop of melted sealing-wax so that the egg may hang suspended with its greater diameter horizontal. Three or four such insulated conductors will be found convenient. Sometimes it is convenient for each egg to have two thread supports. Place a loop or ring at the free end of each thread. When the loops are placed on a horizontal rod (*e. g.*, a piece of glass tubing), the greater diameters of the suspended eggs should lie in the same straight line. An elongated conductor, like A B of Fig. 88, may be made by hanging two or three egg conductors so that they are in contact.

223. A Neutral Line.—If an insulated conductor, bearing a number of pith ball (or paper) electroscopes, be brought near an electrified body, C, (Fig. 88), but not near enough for a spark to pass between them, the pith balls near the ends of the conductor will diverge, showing the presence of separated or uncombined electricity. The pith balls at the middle of the conductor will not diverge, marking thus a neutral line.

This action will take place across a considerable distance even if a large sheet of glass be held between A and C.

If C has a positive charge, the charge at A will be negative and that at B will be positive, as may be shown by charging an electric pendulum and testing at A and B, as shown in Fig. 88.

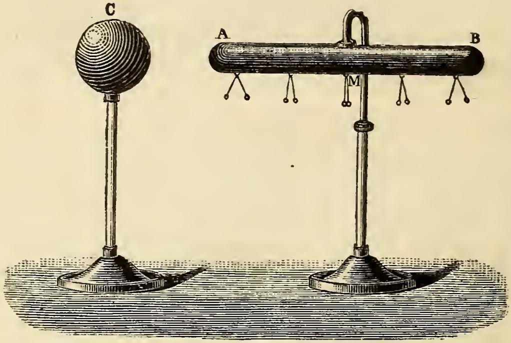

FIG. 88.

If C be removed or "discharged" by touching it with the hand, all traces of electrical separation in A B will disappear. The charged pith ball will be attracted at every point of A B.

224. Charging a Body by Induction. — If the polarized conductor be touched with the hand, or otherwise placed in electric communication with the earth, the electricity repelled by C (Fig. 88), will escape, and the pith balls at B will fall together. The electricity at the other end will be held by the mutual attraction between it and its opposite kind at C. The line of communication with the ground being broken and the conductor being removed from the vicinity of C, the latter will be found charged with electricity opposite in kind to that of C.

A body may be thus charged by induction with no loss to the inducing body.

225. Polarization Precedes Attraction. — When an electrified glass rod is brought near an insulated uncharged pith ball (electric pendulum), the pith ball is polarized, as shown in the figure. As the — of the ball is nearer the + of the glass than is the + of the ball, the attraction is greater than the repulsion.

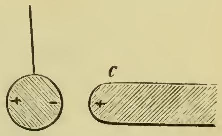

FIG. 89.

If the pith ball be suspended, not by a silk thread but by some good conductor, the attraction will be more marked, for the + of the ball will escape to the earth through the support and the repelling influence thus removed.

226. Provisional Theory of Electricity.—While the real nature of electricity remains unknown, the following theory will be found convenient for classifying results already attained and suggesting directions for further inquiry. But we must not let it influence our judgment as to what is the true and full explanation of electrical phenomena, which explanation may be found hereafter :

We may assume that a neutral or unelectrified body contains equal and equally distributed quantities of positive and of negative electricity.

We may assume these electricities to be unlimited in amount.

We shall then conceive that a positively elec-

trified body has an excess of + electricity and that a negatively electrified body has an excess of − electricity.

In this light, we shall see that communicating + electricity to a body is equivalent to removing an equal amount of − electricity from it, and conversely.

227. The Electrophorus.—This simple instrument consists generally of a shallow tinned pan filled with resin, on which rests a movable metallic cover with a glass or other insulating handle. The resinous plate may be replaced by a piece of vulcanized India-rubber. The metal surface and the resinous surface touch at only a few points; they are practically separated by a thin layer of air.

FIG. 90.

(*a.*) The resinous plate may be prepared by melting together equal quantities of rosin and Venice turpentine and then adding a like quantity of shellac. The substances should be heated gradually and stirred together so as to prevent the forming of bubbles. Take care that the mixture does not take fire in course of preparation. The Venice turpentine is desirable but not necessary. For a handle, a stout wire may be soldered to the centre of the disc and covered with rubber tubing; or a piece of sealing-wax, of convenient size, may be fastened to the disc for the purpose. A still better plan is to make the cover of wood, a little less in

diameter than the resinous plate and with its edges carefully rounded off. For a handle, a glass rod or tube may be tightly thrust or cemented into a hole in the middle of the cover. Paste tin-foil all over the cover and smooth down all rough edges of the foil with the finger nail or a paper folder. The wire support for a pith ball or paper electroscope may be thrust into the wood of the cover, care being taken that it touches the tin-foil.

(*b.*) The plate is rubbed or struck with flannel or catskin, and thus negatively electrified. The cover is then placed upon the resin and thus polarized by induction. Touch the cover with the finger, as shown in Fig. 90; the free – electricity escapes and the leaves fall. The cover is now charged positively. The charged cover will give a spark to the knuckle or other unelectrified body presented to it. (Fig. 91.)

228. The Electrophorus charged by Induction.—The cover may be thus charged and discharged an indefinite number of times, in favorable weather, without a second electrifying of the resinous plate. This could not happen if the electricity of the cover were drawn from the plate. Moreover, if the charge of the cover were drawn

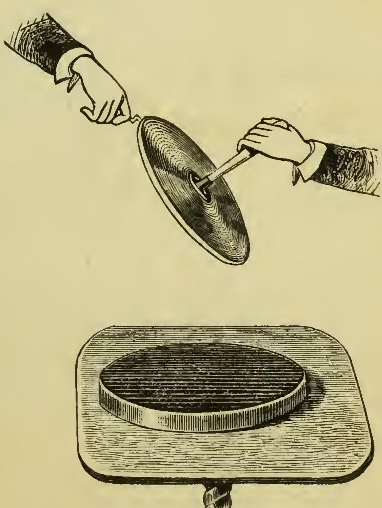

FIG. 91.

from the plate, it would be —, and not +. *The cover is charged by induction and not by conduction.*

229. Whence this Energy ?—At every discharge of the electrophorus, it gives a definite amount of electricity, capable of doing a definite amount of work. As this is obtained not by the expenditure of any part of the original charge, we are led to seek for the source of *this apparently unlimited supply of energy.*

"As a matter of fact, it is a little harder work to lift the cover when it is charged with the + electricity than if it were not charged for, when charged, there is the force of the electric attraction to be overcome as well as the force of gravity. Slightly harder work is done at the expense of the *muscular energies* of the operator and this is the real origin of the energy stored up in the separate charges."

230. A Charge Resides on the Surface.—Many experiments have been made showing that *when a conductor is electrified, the electricity passes to the surface and escapes if the body be not insulated.*

Experiment 92.—Place a carrot horizontally upon an insulating support. Into one end of the carrot stick a sewing-needle. Bring the electrified glass rod near the point of the needle without touching it. The — electricity of the carrot quietly escapes from the point to the rod and the carrot is charged with the + electricity that remains.

231. Density. — Experiments show that when a spherical conductor is charged, the electricity is evenly distributed over the surface, provided no other electrified

body be near. The electric density is the same at every point.

Experiments on an elongated cylinder, like the prime conductor of the electric machine, show that the density is greater at the ends. On an egg-shaped conductor, like that shown in Fig. 92, the density is greatest at the smaller end.

In general, the electric density is very great at any pointed part of a charged conductor.

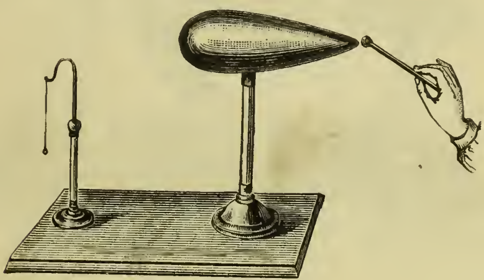

FIG. 92.

This density at a point may become so great that the electricity will escape rapidly and quietly, the air particles rapidly carrying off the charge by convection. This explains the action of points, which plays so important a part in the action of electric machines.

232. Electric Machines. — Machines have been made for developing larger supplies of electricity more easily than can be done with a rod of glass or sealing-wax or with the electrophorus. Each of them consists of one part for producing the electricity and another part for collecting it.

233. The Plate Electric Machine.—This instrument is represented in Fig. 93. It consists of an insulator (or electric), a rubber, a negative and a positive or prime conductor. The electric is a glass (or ebonite) plate, *A*, generally one, two or three feet in diameter.

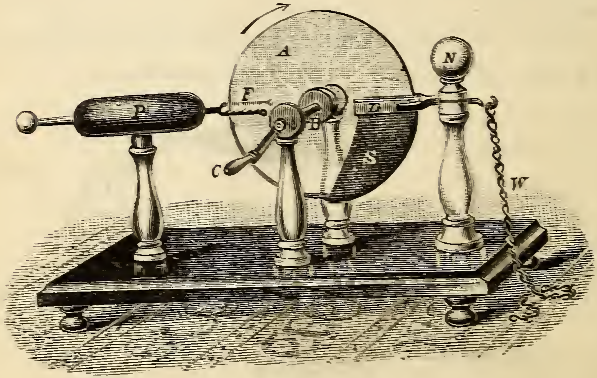

Fig. 93.

This plate has an axis, *B*, and handle, *C*, and is supported upon two upright columns. The rubber, *D*, is made of two cushions of silk or leather, covered with amalgam (see § 197, *a*). They press upon the sides of the plate and are supported from the negative conductor, with which they are in electric connection.

The negative conductor, *N*, is supported upon an insulating column and, when only positive electricity is desired, is placed in electrical connection with the earth by means of a chain or wire, *W*. The prime conductor, *P*, is insulated. One end of the prime conductor termi-

nates in two arms, *F*, which extend one on either side of the plate. These arms, being studded with points projecting toward the plate, are called *combs*. The teeth of the combs do not quite touch the plate. A silk bag, *S*, is often supported so as to enclose the lower part of the plate. All parts of the instrument except the teeth of the combs are carefully rounded and polished, sharp points and edges being avoided to prevent the escape of electricity as already explained. This avoiding of points and edges is to be regarded in all apparatus for use with electricity of high potential.

(*a*.) The pupil may make a plate machine without much expense. A glazier will cut for him a disc of plate glass, possibly from a fragment on hand. The edges of this disc may be rounded on a wet grindstone. A hole may be bored in the middle with a round file kept moistened with a solution of camphor in turpentine. The conductors, *N* and *P*, may be made of wood covered with gold foil or Dutch leaf and supported on pieces of stout glass tubing. The prime conductor may well have two such supports. The arms may consist of two stout wires thrust into the end of a prime conductor, their free ends being provided with knobs of lead or other metal. The combs may be made by soldering pin points to one side of each arm. See that the gold foil makes actual contact with the metal arms. See that all metal parts except the pin points are polished smooth. The columns that support the plate may be made of seasoned wood. The part of the handle to which the hand is applied may be made of glass or insulated by covering it with rubber tubing.

234. Operation of the Plate Machine. — The plate is turned by the handle. Electric separation is produced by the friction of the rubbers. The + electricity of the rubber and negative conductor passes to

the plate; the — electricity of the plate passes to the rubber and negative conductor. The part of the plate thus positively charged passes to the combs of the prime conductor. The + of the plate acts inductively upon the prime conductor, polarizes it, repels the + and attracts the — electricities.

Some of the — electricity thus attracted streams from the points of the combs against the glass, while some of the + electricity of the glass escapes to the prime conductor. This neutralizes that part of the plate and leaves the prime conductor positively charged.

The rubber and negative conductor are kept in equilibrium by means of their connection with the earth. As the plate revolves, the lower part, passing from *N* to *P*, is positively charged; the upper part, passing from *P* to *N*, is neutralized. If negative electricity be desired, the chain or other ground connection is changed from *N* to *P*, and the charge taken from *N*.

NOTE.—Other forms of electric machines are made. One of the latest of these, known as the Toepler-Holtz, is very compact and efficient and remarkably free from the limitations of atmospheric conditions. It may be described as a continuously acting electrophorus (§ 227). A very good one may be bought of JAMES W. QUEEN & CO., of Philadelphia, for $25 or more. One should be provided for the school *in some way* if possible. Any electrical machine should be free from dust and perfectly dry when used. It should be warmer than the atmosphere of the room, that it may not condense moisture from the surrounding air. The dryer the atmosphere the better will be the action of the machine.

235. Construction of the Leyden Jar. —The Leyden jar consists of a glass jar, coated within and with-

out for about two-thirds its height with tin-foil, and a metallic rod, communicating by means of a small chain with the inner coat and terminating above in a knob. The upper part of the jar and the cork which closes the mouth of the jar and supports the rod are generally coated with sealing-wax or shellac varnish to lessen the deposition of moisture from the air.

FIG. 94.

(*a.*) Select a candy or fruit jar of greenish glass; paste tin-foil within and without, as above described, using flour paste; thrust a wire through a dry cork; bend the wire so that, when the cork is in its place, the wire shall touch the tin-foil on the side of the bottle without tearing it; solder the upper end of the wire to a smooth button or thrust it into a lead bullet; charge *your Leyden jar* with a few sparks from the electrophorus and take a shock.

236. Charging the Leyden Jar.—To charge the jar, hold it in the hand, as shown in Fig. 95, and bring the knob near or into contact with the prime conductor of an electrical machine which is in action.

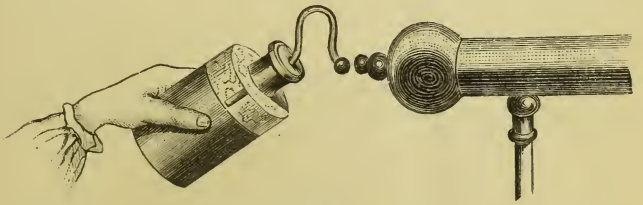

FIG. 95.

237. Discharging the Leyden Jar. — The jar might be discharged by touching the knob with the

8

finger. In this case the experimenter will feel a "shock." If the charge be intense, the shock will be painful or even dangerous. It is better to use a "discharger," one form of which is represented in Fig. 96. This consists of two metal arms hinged together, carrying knobs at their free ends and carried by insulating handles. The outer coat should be touched first.

FIG. 96.

(*a.*) A good discharger may be made by passing a piece of stout copper wire, about a foot long, through a piece of rubber tubing and providing a metal knob for each end of the wire. The flexibility of the wire avoids the necessity for a hinged joint.

238. Modes of Discharge. — An electrified conductor may be discharged in at least three ways, *viz.*, by the *disruptive* discharge, by the *convective* discharge and by the *conductive* discharge.

The discharge in any of these ways is accompanied by a transformation of energy, sound, light, heat, chemical action and other phenomena being produced.

Experiment 93.—Present a knuckle of the hand or a metal knob to the prime conductor of an electric machine and "draw sparks" therefrom.

239. The Disruptive Discharge.—A discharge of electricity taking place suddenly through a non-conductor is called a disruptive discharge, *e. g.*, the sparks drawn from an electric machine in action.

Experiment 94.—Attach a pointed wire to the prime conductor of the electric machine. The flame of a candle held near will be blown away, as shown in Fig. 97. If the candle be placed upon the prime conductor and a pointed conductor be held in the hand near the candle, the flame will still be blown away.

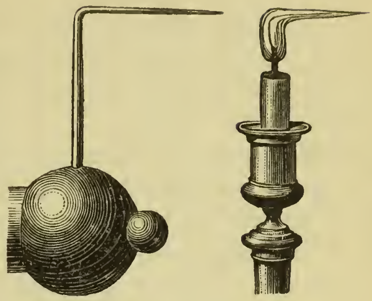

FIG. 97.

240. The Convective Discharge.—When electricity of high potential accumulates with so great a density as to electrify the neighboring particles of air which, driven by electric repulsion, fly off carrying part of the charge with them, we have what is called the convective discharge. Such discharges are best manifested in gases at low pressure, in tubes exhausted by an air-pump.

241. The Conductive Discharge.—The flow of a continuous current of electricity constitutes the conductive discharge.

When electricity flows through a wire from the prime conductor of an electric machine to the rubbers or from the positive pole of a voltaic cell or battery to the negative, we have a conductive discharge. It will be considered in the section especially devoted to voltaic electricity.

242. Lightning.—When an electrified cloud floats over the earth, separated from it by a layer of insulating

air, the inductive influence of the cloud renders the ground beneath oppositely electrified. Then the cloud, ground and insulating air correspond respectively to the inner and outer coatings and the insulating glass of a Leyden jar.

As the charge of a Leyden jar may be made so intense that the attraction of the separated electricities will result in their rushing together and thus piercing the jar, so the charge of a cloud may become sufficiently intense to overcome the resistance of the air and a lightning stroke ensues. Such electric sparks are sometimes more than a mile in length but the duration is not more than 0.00001 of a second.

243. Lightning-Rods.—The value of lightning-rods depends upon the tendency of electricity to follow the best conductor, and upon the effect of pointed conductors upon electrical density (§ 231).

The lightning-rod should be made of a good conductor; copper is better than iron. It should terminate above in one or more points, tipped with some substance that can be corroded or fused only with extreme difficulty. Platinum or iridium is a metal which satisfies these conditions very well.

The rod should extend above the highest point of the building in order to offer the electricity the shortest path to the ground. It is important to have each projecting part of the building, as chimneys, towers and gables, protected by a separate rod. All metal work about the roofs or chimneys should be connected with the rod.

The rod should afford an unbroken connection; the joints, if there be any, should be carefully made.

The rod should terminate below in water or in earth that is *always* moist. It is well to connect the rod with underground water-pipes when possible or with a large metal plate. *Personal attention* should be given to this matter when the rod is put up as, being under ground and out of sight, this part of the rod is not easily inspected subsequently.

A rod having a blunted tip, a broken joint or terminating in dry earth is more dangerous than no rod at all. Lightning-rod insulators are undesirable.

(*a.*) The greatest value of a lightning-rod is due to its quiet work in the *prevention* of the lightning stroke. Bring the point of a knife-blade near the conductor of an electric machine in operation and notice the instant cessation of sparks. The quiet passage of electricity from the earth neutralizes the charge of the conductor and restores the electric equilibrium. In the same way, a lightning-rod tends to restore the electric equilibrium of the cloud and prevent the dangerous discharge. For this quiet but very valuable service, few persons ever give the rod any credit. Every leaf of the forest and every blade of grass is a pointed conductor acting in the same way. (§ 231.)

NOTE.—It is neither necessary nor very desirable that all of the following experiments be performed. Several of them involve the same principle; but one school may have one piece of apparatus and another, another piece. Additional experiments may be found in *The Elements of Natural Philosophy.*

Experiment 95.—Figure 98 represents the "electric bells." The metal frame is hung from the prime conductor. The right-hand bell is suspended by a wire; the other bell is suspended by a silk cord and connected with the ground by means of a chain hanging on the floor. Work the machine slowly; the clapper vibrates and rings the bells. *Explain.*

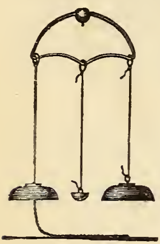
FIG. 98.

Experiment 96.—Place the two ends of a pane of window glass upon two books so that the pane shall be about two inches above the surface of a table. Place several pith balls or numerous bits of tissue paper on the table under the glass. Electrify the glass by rubbing its upper surface with silk. Notice the lively motions of the balls or paper bits.

Experiment 97.—Electrify a glass rod. Toss a small sheet of gold leaf into the air. Bring the rod near the leaf. The leaf is drawn toward the rod and then thrown off. Chase the leaf with the rod without letting it touch the ground. *Explain.*

Experiment 98.—If a pupil, standing upon an insulating stool (a board supported by four warm tumblers will answer) and having one hand upon the prime conductor of an electric machine in action, bring a knuckle of the other hand near one end of the balanced yard-stick Experiment 73, it will follow the knuckle. *Explain.*

Experiment 99.—Place a few bits of paper upon the cover of the electrophorus When the cover has been touched with the

finger and lifted by the insulating handle, the paper will be thrown off. *Explain.*

Experiment 100.—Electrify a doll's head covered with long, dry hair. The hairs will stand out, as shown in Fig. 99, producing an exaggerated appearance of fright.

FIG. 99.

Experiment 101.—Vary Experiment 94 by placing the candle on the prime conductor and holding the point of a needle toward it, as shown in Fig. 100. The flame will be driven away by the convective discharge.

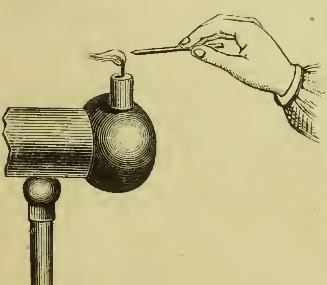

FIG. 100.

Experiment 102. — Fasten one end of a long fine wire to the knob of the electroscope. Charge the disc of the electrophorus and touch it to the other end of the wire. Notice the action of the electroscope. Try the experiment with a dry silk thread instead of the wire. Describe the action of the electroscope. What does this experiment teach about the wire and the thread?

Experiment 103.—Place an "electric whirl" (which consists of a set of horizontal wire arms radiating from a pivot-supported centre, the pointed ends being all bent in the same direction) upon the prime conductor. Work the machine and the arms will revolve. (See Fig. 101.) *Explain.*

FIG. 101.

Experiment 104.—Place a pupil on the insulating stool. Let him hold an electroscope, with his finger on the knob. Let a second pupil strike him on the back with a cat-skin. Notice the leaves of the electroscope at every stroke.

Experiment 105.—Get a smooth board and a sheet of paper. Heat them both before the fire. Place the paper on the board and rub it vigorously with a piece of india-rubber. Remove the electrified paper from the board and hold it near the wall. It will fly to the wall and cling to it for some time.

Experiment 106.—Electrify the paper as in the last experiment. Remove it from the board and hold it by the edges. Let a pupil place a pith ball on the paper. Notice and explain the action of the ball.

Experiment 107.—Electrify the paper as in the last experiment. While it is lying on the board, cut it into narrow strips. Take hold of all the strips at one end and lift them from the board. Notice the repulsion of light bodies similarly charged.

Experiment 108.—Place a pupil upon an insulating stool (a board supported by four warm tumblers will answer) and charge him by giving him twenty or more sparks from the disc of the electrophorus. Let another pupil, not insulated, bring his knuckle to any part of the body of the first pupil. Let the pupils describe the result.

Experiment 109.—Cover one knob of the discharger with gun-cotton sprinkled with powdered rosin. When the Leyden jar is discharged with this discharger, the cotton and rosin are ignited.

Experiment 110.—Let a pupil, standing on an insulating stool, become charged by holding one hand on the prime conductor when the machine is in operation. If he then bring his knuckle to a metal burner from which a jet of gas is issuing, a spark will pass between the knuckle and the burner, igniting the gas. An Argand or Bunsen burner answers well for this experiment. The experiment may be modified by using, instead of the knuckle, an

icicle held in the hand. The gas burner may be replaced by a pupil (not insulated) holding a spoonful of ether or chloroform which readily gives off an easily combustible vapor.

244. Relation of Electricity to Energy. — The work necessarily performed in operating an electric machine is not all expended in overcoming inertia and friction. Much of it is employed in producing electric separation. It matters not whether this separation be the separation of two fluids or of *something* else.

Whatever be the nature of the realities separated, mechanical kinetic energy is employed in the separation and converted into the potential variety (§ 100).

An electrified pith ball or a charged Leyden jar is simply an electrostatical reservoir of potential energy. In the discharging of such a body, the passage of the current is accompanied by a loss of potential energy. What becomes of this energy? This leads us to look for effects due to it, to work done by it.

Many illustrations of work thus done have been furnished in the experiments just described. In every case of electric attraction or repulsion, we have an evident reconversion of this potential energy into mechanical kinetic energy. We shall soon see that the sound, heat and light accompanying electric discharges are forms of energy due to the conversion of the potential energy of electric separation.

We shall see other effects, more or less powerful, when we come to study voltaic and other forms of current electricity.

245. Recapitulation.—To be amplified by the pupil for review.

ELECTRICITY PRODUCED BY FRICTION.

- KINDS AND NAMES.
- ELECTROSTATIC LAWS.
- ELECTROSCOPES.
- CONDUCTION
  - CONDUCTORS.
  - INSULATORS.
  - RESISTANCE.
- POTENTIAL AND E. M. F.
- CAPACITY.
- ELECTRIFICATION.
  - BY CONTACT.
  - BY INDUCTION.
    - *Polarization.*
    - *Electrophorus.*
  - MACHINES.
- DISTRIBUTION OF CHARGE.
  - ON SURFACE.
  - DENSITY.
- LEYDEN JAR.
- DISCHARGE
  - DISRUPTIVE.
  - CONVECTIVE.
  - CONDUCTIVE.
- THUNDER-STORMS
  - LIGHTNING.
  - LIGHTNING-RODS.
- EXPERIMENTS.
- RELATION TO ENERGY.

EXERCISES.

1. Why do we regard the two electric charges produced simultaneously by rubbing together two bodies as being of opposite kinds ?

2. Quickly pass a rubber comb through the hair and determine whether the electricity of the comb is positive or negative.

3. Twist some tissue paper into a loose roll about six inches long. Stick a pin through the middle of the roll into a vertical support. Present an electrified rod to one end of the roll and thus cause the paper to turn about the pin as an axis. Give this piece of scientific apparatus an appropriate name.

4. (*a.*) Prepare two wire stirrups, *A* and *B*, like those shown in Fig. 79, and suspend them by threads. Electrify two glass rods by rubbing them with silk and place them in the stirrups. Bring *A* near *B*. Notice the repulsion. (*b.*) Repeat the experiment with two sticks of sealing-wax that have been electrified by rubbing with flannel. Notice the repulsion. (*c.*) Place an electrified glass rod in *A* and an electrified stick of sealing-wax in *B*. Notice the attraction. Give the law illustrated by these experiments.

5. Why is it desirable that a glass rod used for electrification be warmer than the atmosphere of the room where it is used ?

6. Electrify one insulated egg-shell conductor (§ 222, *b*). Bring it near a second conductor but not into contact with it. Touch the second egg-shell with the finger. (*a.*) Experimentally, determine whether the second egg-shell is electrified or not. (*b.*) If you find that it is, what word explains the method of charging ? (*c.*) If the second egg-shell is charged, will its potential and the potential of the first be of the same or of opposite signs ?

SECTION III.

VOLTAIC AND THERMO-ELECTRICITY.

246. Chemical Action. — All chemical changes (§ 11, *a*,) are accompanied by electric separation. The chemical action between liquids and metals gives results the most satisfactory. Electricity thus developed is called *voltaic or galvanic electricity.*

247. Current Electricity.—The principal classes of electric currents are as follows :

(1.) *Currents produced by chemical action, i. e., voltaic currents.*

(2.) *Currents produced by heat, i. e., thermo-electric currents.*

(3.) *Currents produced by other electric currents or by magnets, i. e., induced currents.*

(*a*.) We have seen that, when a body having an electrical charge is properly connected with another of lower potential, there is a transfer of electricity from the former to the latter. This implies that there is an electric current. But this current is only momentary and of little importance in comparison with the currents that we are about to consider.

(*b*.) Current electricity may differ from static electricity in quantity, electromotive force, *etc., but not in its nature.*

248. The Voltaic Current. — When a strip of copper and one of zinc are placed in dilute sulphuric acid or in a battery solution like the one already used, the two strips being connected above the acid by a wire conductor, a current of electricity is produced. The apparatus here described is called a *voltaic or galvanic element or cell.*

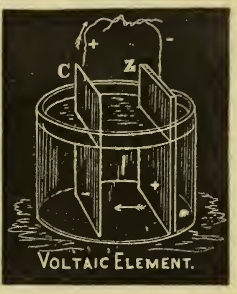

FIG. 102.

(*a.*) For voltaic purposes, the sulphuric acid should be diluted by slowly *pouring the acid* into ten or twelve times its bulk of soft water. Do not pour the water into the acid.

249. Direction of the Current.—The metal most vigorously acted upon by the liquid constitutes the generating or positive plate; the other, the collecting or negative plate.

When the wires from the two plates are in contact, it is said that the *circuit is closed;* when the plates are not thus in electric connection, it is said that the *circuit is broken.*

When the circuit is broken, the ends of the wires are called *poles* or *electrodes.* The negative pole is attached to the positive plate and *vice versa.* Strips of platinum are often fastened to the ends of the wires; these platinum strips then constitute the electrodes.

In the liquid, the current is from the + to the − plate. In the wire, the current is from the

+ to the — electrode. In each case, the current passes from + to —.

The direction of the current is indicated by the arrows in Fig. 102.

250. Internal Resistance.—We may imagine that the two plates of a voltaic cell are connected by a liquid prism. The greater the distance between the plates, the longer this prism and the greater its resistance. The larger the plates, the larger the prism and the less its resistance.

Gases are poor conductors. Hence, the hydrogen bubbles that often adhere to the negative plate increase the internal resistance of the cell by lessening the effective surface of the plate. (§ 272.)

251. The Ampere.—The strength of current or its rate of flow will depend upon electromotive force and resistance, increasing with the former and decreasing with the latter.

The unit of current is called an ampere.

(*a.*) At any given instant, the current is the same at every part of the circuit.

252. Ohm's Law. — The following important formula is known as Ohm's law :

$$\frac{Volts}{Ohms} = Amperes, \text{ or } \frac{E}{R} = C.$$

(*a.*) If we have a difference of potential that secures an E. M. F. of 18 volts and if the total resistance of the circuit be 3 ohms, the strength of the current will be 6 amperes. $18 \div 3 = 6$.

253. The Coulomb. — *The unit of quantity is called the coulomb. It is the quantity of electricity given by a one ampere current in one second.*

(*a.*) A 10 ampere current will give 30 coulombs in 3 seconds.

254. Amalgamating the Zinc. — Ordinary commercial zinc is far from being pure. The chemically pure metal is expensive. When impure zinc is used, small closed circuits are formed between the particles of foreign matter and the particles of zinc. This *local action,* which takes place even when the circuit of the cell or battery is broken, rapidly destroys the zinc plate and contributes nothing to the general current. This waste is prevented by frequently amalgamating the zinc. This is done by cleaning the plate in dilute acid and then rubbing it with mercury. See *Elements of Natural Philosophy,* § 386, *a.*

255. Polarization.—It was stated in § 250 that the accumulation of hydrogen bubbles at the negative plate increases the internal resistance of the cell. But the hydrogen affects the current in another way. It acts like a positive plate (being almost as oxidizable as the zinc) and sets up an opposing electromotive force which tends to set a current in the opposite direction.

A cell or battery in this condition is said to be polarized.

Sometimes, as a result of polarization, the strength of the current falls off very greatly within a few minutes after closing the circuit.

256. Varieties of Voltaic Cells.—All voltaic cells belong to one of two classes:

(1.) *Those using only one liquid.*

(2.) *Those using two liquids.*

All of the earlier batteries were composed of one-fluid cells.

257. Smee's Cell.—A Smee's cell is represented by Fig. 103. It consists of a platinized silver plate placed between two zinc plates hung in dilute sulphuric acid. The hydrogen bubbles accumulate at the points of the rough platinum surface and are more quickly carried up to the surface of the liquid and thus gotten rid of. The cell has an electromotive force of about 0.65 volts.

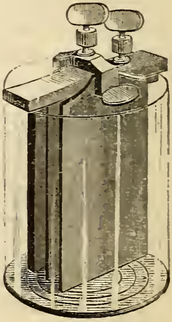

Fig. 103.

258. Potassium Di-chromate Cell.—The potassium di-chromate cell has a zinc plate hung between two carbon plates. A solution of potassium di-chromate in dilute sulphuric acid is the liquid used. The hydrogen is given an opportunity for chemical union as fast as it is liberated.

The E. M. F. of this cell is great to start with (from 1.8 to 2.3 volts) but it falls very quickly when the external resistance is small. It quickly recovers and may be used with advantage where powerful currents of short duration are wanted. It is the only single fluid cell that is free from polarization.

(*a.*) The bottle form of this cell, represented in Fig. 104, is the most convenient for the laboratory or lecture table. By means of the sliding rod, the zinc plate may be raised out of the solution when not in use. Thus adjusted, the cell may remain for months without any action, if desired, and be ready at a moment's notice.

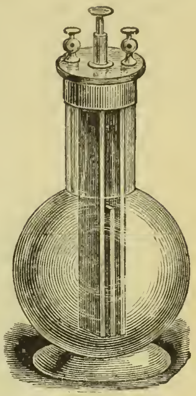

Fig. 104.

(*b.*) One of the best proportions for the solution is as follows: One gallon of water, one pound of di-chromate of potash, and from a half pint to a pint of sulphuric acid, according to the energy of action desired. A small quantity of nitric acid added to the solution increases the constancy of the battery.

259. The Leclanche Cell.— This cell, shown in Fig. 105, contains a zinc plate or rod and a porous earthenware cup filled with carbon and peroxide of manganese. This cup replaces the other metal plate. The liquid used is a solution of ammonium chloride (sal ammoniac) in water.

This cell is tolerably constant if it be not used to produce very strong currents, but its great merit is that *it is very permanent*. It will keep in good condition for months with very little attention, furnishing a current *for a short time* whenever wanted. It is much used for working telephones, electric bells (see *H* in Fig. 105) and clocks, railway signals, *etc.*

The manganese oxide prevents polarization by destroying the hydrogen bubbles. If the cell be used continuously for some time, the power of the cell weakens owing to the accumulation of hydrogen, but if left to itself it

gradually recovers as the hydrogen is oxidized. Sometimes the manganese oxide is applied to the face of the carbon and the porous cup dispensed with. This cell has an E. M. F. of about 1.5 volts. *It should be left on open circuit when not in use.*

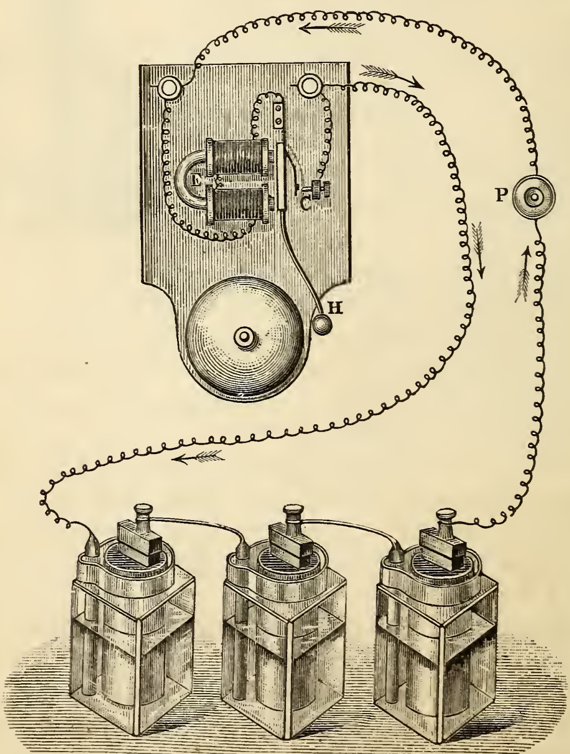

FIG. 105.

260. Daniell's Cell.—This cell consists of a copper plate immersed in a saturated solution of copper sulphate (blue vitriol) and a zinc plate immersed in dilute sulphuric acid or a solution of zinc sulphate (white vitriol). The two liquids are separated; usually one liquid is contained in a porous cup placed in the other liquid. Large crystals of copper sulphate are placed on a perforated shelf in the solution of copper sulphate to keep the latter saturated.

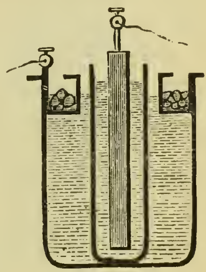

FIG. 106.

Such a cell will furnish a nearly constant current, with an E. M. F. of 1.079 volts and keep in order for a long time. *It should be kept on closed circuit when not in use.*

The outer cell is sometimes made of copper and serves as the copper plate, as is shown in Fig. 106. The hydrogen passes through the porous cell and acts upon the solution of copper sulphate. Copper, instead of hydrogen, is deposited upon the copper plate. Polarization is thus avoided.

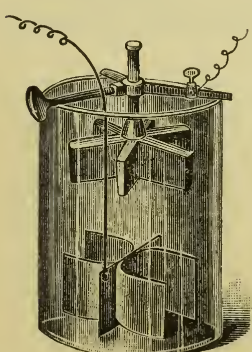

FIG. 107.

261. The Gravity Cell.—This is a modification of the Daniell's cell, no porous cup being used. The copper plate is placed at the bottom of the cell and the zinc plate near the

top. Crystals of copper sulphate are piled upon the copper plate and covered with a saturated solution of copper sulphate. Water or, preferably, a weak solution of zinc sulphate rests upon the blue solution below and covers the zinc plate. The two solutions are of different specific gravities and remain clearly separated if the cell be kept on closed circuit when not in use. (Fig. 107.)

This cell is very largely used in working telegraph lines. It is sometimes called the Callaud cell.

262. Grove's Cell.—The outer vessel of a Grove's cell contains dilute sulphuric acid. In this is placed a hollow cylinder of zinc. Within the zinc cylinder is placed a porous cup containing strong nitric acid. The negative plate is a strip of platinum placed in the nitric acid. The hydrogen passes through the porous cup and reduces the nitric acid to nitrogen peroxide, which escapes as brownish-red fumes. These nitrogen fumes are disagreeable and injurious; it is well, therefore, to place the battery in a ventilating chamber or outside the experimenting room.

The E. M. F. of the Grove cell, under favorable conditions, is nearly two volts, while its internal resistance is small, being about one-fifth that of a Daniell's cell.

It is much used for working induction coils (§ 306), for generating the electric light, *etc.* It is, however, troublesome to fit up and should have its liquids renewed every day that it is used. Fig. 109 represents a Grove's battery with cells *joined in series.*

263. Bunsen's Cell.—Bunsen's cell (Fig. 108) differs

from Grove's in the use of carbon instead of expensive platinum for the negative plate, thus reducing the cost. The plates are made larger than for Grove's battery.

Its E. M. F. is about the same as that of the Grove cell but its internal resistance is greater. Fig. 110 represents a battery of Bunsen's cells *joined in multiple arc.*

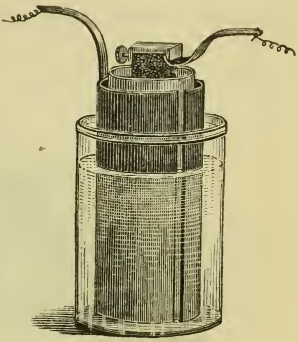

Fig. 108.

264. A Voltaic Battery.—*A number of voltaic elements connected in such a manner that the current has the same direction in all, constitutes a voltaic battery.*

The usual method is to connect the positive plate of one element with the negative plate of the next, as shown in Fig. 109. When thus connected, they are said to be coupled "tandem" or "in series." Sometimes all of the positive plates are connected by a wire and all of the negative plates by another wire. The cells are then said to be joined "parallel," "abreast" or "in multiple arc." (See Fig. 110.)

(*a.*) When two or more cells are joined together, the points of contact should be as large as is convenient and kept perfectly clean. The connecting wire should be of good size and, for the sake of pliability, a part of it may well be given a spiral form by winding it upon a pencil or other small rod.

265. Batteries of High Internal Resistance.—Each kind of galvanic cell has an internal resistance, as explained in § 250. A battery of cells joined in series is called a "battery of high internal resistance." (Fig. 109.) This method of joining the cells increases the length of the liquid conductor through which the current passes.

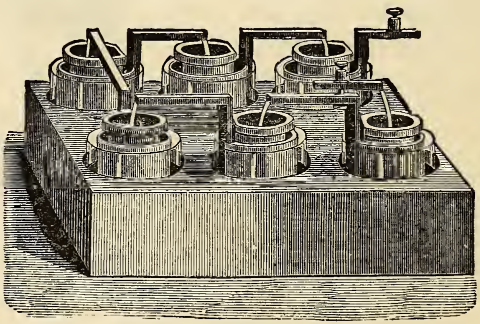

Fig. 109.

(*a.*) In a battery of cells joined in series, the E. M. F. and the internal resistance are those of a single cell multiplied by the number of cells.

266. Batteries of Low Internal Resistance.—A battery of cells joined parallel is called a "battery of low internal resistance." (Fig. 110.) This method of joining the cells does not increase the length of the liquid conductor traversed by the current but is equivalent to increasing its diameter or area of cross section.

For a circuit of great external resistance, a battery of high internal resistance is needed. For a circuit of

small external resistance, large cells, or several cells joined parallel are preferable.

(*a.*) In a battery of cells joined parallel, the E. M. F. is that of a single cell but the internal resistance is that of a single cell divided by the number of cells.

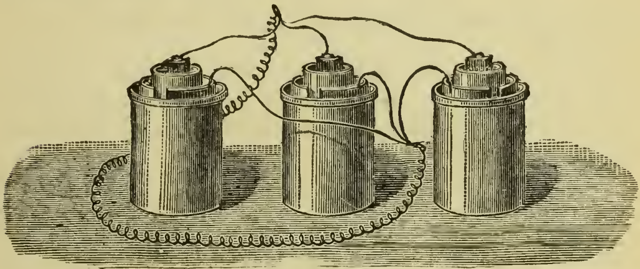

FIG. 110.

(*b.*) A battery of high internal resistance was formerly called an *intensity* battery, while a battery of low internal resistance was called a *quantity* battery.

267. The Best Arrangement of Cells.—The best method of coupling cells depends on the work to be done by the battery. *The maximum effect is attained when the internal resistance of the battery is equal to the resistance of the external circuit.* For example, suppose that in a given battery of eight cells:

(1.) Each cell has an E. M. F. of two volts.

(2.) Each cell has the very high internal resistance of eight ohms.

(3.) The battery is to work through a wire that has a resistance of sixteen ohms.

(*a.*) First, couple the cells parallel. The E. M. F. of the battery is that of a single cell, 2 volts. The internal resistance is 8 ohms $\div 8 = 1$ ohm. Adding the external resistance, we have a total resistance of 17 ohms. (See § 252.)

$$C = \frac{E}{R} = \frac{2}{1 + 16} = 0.1176+.$$

This arrangement gives us a current of 0.1176+ amperes.

(*b.*) Next, couple the cells in series. The E. M. F. of the battery is 8 times 2 volts, or 16 volts. The internal resistance is 8 times 8 ohms or 64 ohms. Adding the external resistance, we have a total resistance of 80 ohms.

$$C = \frac{E}{R} = \frac{16}{64 + 16} = 0.2.$$

This arrangement gives us a current of 0.2 amperes.

(*c.*) Finally, join the cells in two rows of four cells each in series and join the rows parallel. The E. M. F. of the battery will be 4 times 2 volts or 8 volts. The internal resistance will be 4 times 8 ohms or 32 ohms for each row, but only half that, or 16 ohms, for the whole battery. Adding the external resistance, we have a total resistance of 32 ohms.

$$C = \frac{E}{R} = \frac{8}{16 + 16} = 0.25.$$

This arrangement, in which the internal and the external resistances are equal, gives us a current of 0.25 amperes, the greatest possible under the given conditions.

(*d.*) A similar application of Ohm's law shows that *when the external resistance is large, there is little gain from joining cells parallel and that when the external resistance is very small, there is little gain in joining cells in series.*

Experiment III.—From the poles of a potassium di-chromate battery, lead two stout copper wires and connect their free ends by

two or three inches of *very fine iron wire.* Coil the iron wire around a lead-pencil and thrust a small quantity of gun-cotton into the loop thus formed. Plunge the zinc plate of the battery into the liquid and the iron wire will be heated enough to explode the gun-cotton; it may be heated to redness or even fusion.

The resistance of iron wire is about seven times as great as that of a similar copper wire; in other words, its conducting power is only about one-seventh as great. The decrease in the size of the wire also adds to its resistance.

268. Thermal Effects of the Electric Current. —Whenever an electric current flows through a conductor, part of the electricity is changed into heat.

Electric energy is changed into heat energy. The amount of electricity thus changed into heat will depend upon the amount of resistance offered by the conductor.

In the last experiment, the stout copper wires were good conductors, offered but little resistance and converted but little of the electrical energy into heat energy. The change of material from copper to iron increased that resistance. This increased resistance was again increased by reducing the size of the conductor. For this double reason, the *fine wire* offered so much resistance that a considerable of the current energy was transformed into heat.

Resistance in an electric circuit always produces heat at the expense of the electric current.

Thus, electricity is often used in firing mines in military operations and in blasting. All known metals have been melted in this way.

269. Luminous Effects of the Electric Current.—When an electric circuit is closed or broken, there is a spark at the point of contact, due to the heating of a part of the conductor to incandescence. We have seen luminous effects produced by winding the wire from one plate of a voltaic cell around one end of a file and drawing the other electrode along the side of the file, thus rapidly closing and breaking the circuit.

If the iron wire used in the last experiment was heated sufficiently, it also gave a luminous effect and illustrated the fundamental principle of the incandescent electric lamp.

(*a.*) The most important luminous effects of electricity will be considered in connection with dynamo electric machines (§ 311). It will be noticed that all of these are secondary thermal effects.

270. Physiological Effects of the Electric Current.—An electric current may produce muscular convulsions in a recently killed animal. Experiments with the Leyden jar and the induction coil (§ 306) show that similar effects may be produced upon the living animal.

Electricity is largely used as an agent for the cure of disease; experiments of this kind may do injury and would better be left to the educated physician. The discharge of a large battery may be fatal and a number of persons have lost their lives within the last few years by coming, accidentally or otherwise, into the circuit of a dynamo-electric machine.

271. Chemical Effects of the Electric Current.—Many chemical compounds in solution may be decom-

posed by forcing the current to traverse the solution. Substances which are thus decomposed are called *electrolytes;* the process is called *electrolysis;* the compound is said to be *electrolyzed.*

The electrolysis of acidulated water is easily accomplished with a current from two Grove's or Bunsen's cells. (See *Chemistry*, Experiment 12.) The water is decomposed into oxygen and hydrogen.

The apparatus, shown in Fig. 111, may be called a *water-voltameter.*

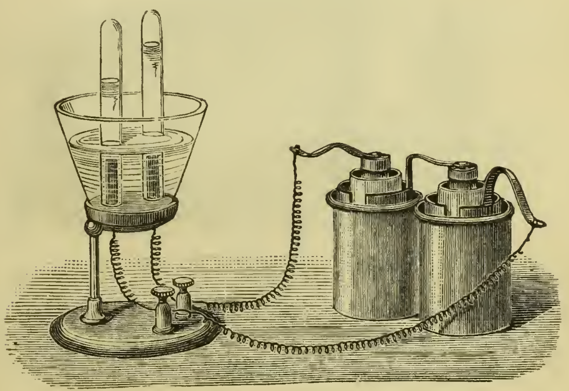

FIG. 111

272. Ions.—The products of electrolysis, like the oxygen and hydrogen, are called *ions;* the one that goes to the + electrode (or anode) is called the *anion:* the one that goes to the — electrode (kathode or cathode) is called the *kathion* or *cathion.*

Experiment 112. — From the + pole of a voltaic battery or dynamo-electric machine, suspend a plate of copper; from the − pole, suspend a silver coin. Place the copper and silver electrodes in a strong solution of copper sulphate (blue vitriol). When the circuit is closed, the salt of copper is electrolyzed, the copper from the salt being deposited upon the silver coin and the sulphuric acid going to the copper or + electrode. The silver is thus electro-plated. (Fig. 112.)

The countless applications of this process of depositing a metallic coat on a body prepared for its reception, constitute the important art of electro-metallurgy.

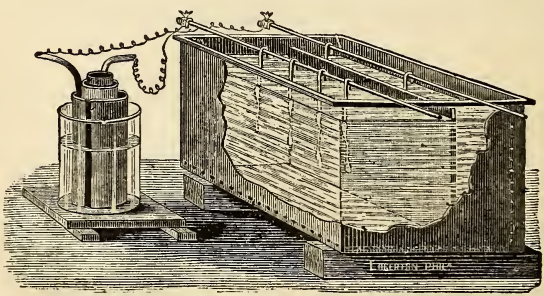

Fig. 112.

273. The E. M. F. of Polarization.—The products of electrolysis have a tendency to reunite by virtue of their chemical affinity. (*Chemistry*, § 8.) For example, the electrolysis of zinc sulphate gives zinc and sulphuric acid. But we now well know that the chemical action of these two substances has an electromotive force of its own. This E. M. F. of the ions acts in opposition to that of the electrolyzing current. In some cases, it rises higher than the E. M. F. of the original current *and reverses the direction of the current.*

The oxygen and hydrogen, yielded by the electrolysis of water (§ 271), tend to reunite and set up an opposing E. M. F. of about 1.45 volts. Thus we see that it requires a battery or cell with an E. M. F. of more than 1.45 volts to decompose water.

This electromotive force of the ions is called the E. M. F. of Polarization.

It may be observed by putting a galvanometer in the place of the battery of the water-voltameter (Fig. 111). The polarization in a voltaic cell acts in the same way.

(*a.*) There is no opposing E. M. F. of polarization when the kathion and the anode are of the same metal. For example, the feeblest current will deposit copper from a solution of copper sulphate, *when the anode is a copper plate.*

274. Secondary Batteries.—When a voltameter or an electro-plating bath is supplying a current of electricity, as mentioned in the last paragraph, it constitutes a secondary battery. As the ions do not reunite when the circuit is open, the energy of the decomposing current may be *stored up* as energy of chemical affinity.

When a current is again wanted, the circuit may be closed and the energy of chemical affinity at once appears as energy of electric current. Secondary batteries are, consequently, often called storage batteries.

(*a.*) The Faure battery consists of two plates of sheet lead coated with red lead (lead oxide). These plates are separated by a layer of paper or cloth, rolled up in a loose coil like a roll of carpet and immersed in dilute sulphuric acid.

(*b.*) When a current from a dynamo-electric machine or a voltaic battery is sent through such a cell, chemical action is produced. Oxygen acts on the coating of the anode plate and converts it into a higher oxide of lead. Hydrogen unites with the coating of the kathode plate and reduces it to metallic lead. When these changes have gone as far as possible, the battery is said to be "charged." The charged plates will remain in this condition for days *if the circuit be left open.*

(*c.*) By closing the circuit, the plates will, at any time, furnish a current until they are changed to their original chemical condition. As the lead plates and the acid are not rapidly destroyed, the battery may be charged and discharged many times.

(*d.*) Many serious defects in the Faure battery have been obviated in the Brush battery, which is the only one yet used to any considerable extent in this country. A Brush dynamo-electric machine (§ 311) is operated in the daytime for charging the batteries. At night, the same dynamo may be used for operating arc electric lights (§ 313), while the charged secondary battery is furnishing the current for the incandescent electric lights. The E. M. F. of each Brush cell is about two volts. For electric lighting, they are generally prepared in batteries of twenty or more cells.

275. Magnetic Effects of the Electric Current.—Any conductor is rendered magnetic by passing a current of electricity through it. We have already seen that a bar of soft iron may be temporarily magnetized by the influence of the voltaic current. It may be further shown by the action of the bar and helix.

(*a.*) The bar may be a straight piece of stout iron wire; the helix may be made by winding cotton covered copper wire upon a piece of glass tubing large enough to admit the wire and not quite as long as the iron.

(*b.*) A good helix, convenient for many purposes, may be made upon an ordinary wooden spool. With a sharp knife, make the shank of the spool as thin as possible and then wind the spool full of insulated copper wire about as large as ordinary broom or stove-pipe wire. The iron bar must be small enough to pass easily through the hole in the spool and long enough to project a lltle ways beyond each end.

(*c.*) Either of these helices may be placed in the circuit of a cell and held in a vertical position, when it will act as a "sucking" magnet. The movable iron core will be held in mid-air "without any visible means of support."

(*d.*) The "helix and ring armature," is shown in Fig. 113. The armature is of soft iron divided into two semicircles with brass handles. When the helix is placed in a closed circuit, the semicircles resist a considerable force tending to draw them apart; when the circuit is broken they fall asunder of their own weight The iron ring may be made without handles by any blacksmith. Stout cords will answer for handles. The helix may be made by winding insulated wire upon a pasteboard cylinder an inch or an inch and a half long. There should be four or five layers of the wire which may be tied together with strings passing through the hole in the helix.

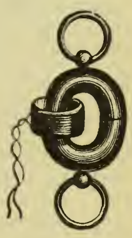

Fig. 113.

(*e.*) Such temporary magnets as these are called electro-magnets. The subject of electro-magnets will be further considered in §§ 298–300.

276. The Electric Telegraph.—The electric telegraph consists essentially of an electro-magnet and a "key" placed in the circuit of a battery. The key is an instrument by which the circuit may be easily broken or closed at will. The armature, *A*, of the magnet, *M*, is

supported by a spring, S, which lifts it when the circuit is broken. When the circuit is closed, the armature is drawn down by the attraction of the magnet. Thus the armature may be made to vibrate up and down at the will of the person at the key. The armature may act upon one arm of a lever, the other end of which, being provided with a style or pencil, P, may be pressed against a paper ribbon, R, drawn along by clock-work.

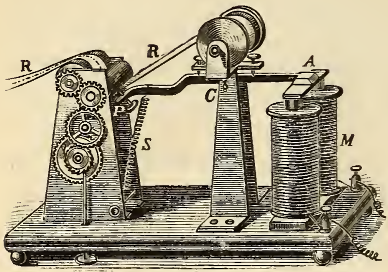

Fig. 114.

Thus the pencil may be made to record, upon the moving paper, a series of dots and lines at the pleasure of the operator at the key perhaps hundreds of miles away. When the two stations are several miles apart, one of the wires is dispensed with, the circuit being completed by connecting each station with the earth.

The inventor of the practical electric telegraph was an American, S. F. B. Morse. The system of signals devised by him is given in the *Elements of Natural Philosophy*, § 396.

To prevent confusion, a small space is left between successive letters, a longer one between words, and a still longer one between sentences. Telegraph operators soon become so familiar with this alphabet that they understand a message from the mere clicks of the lever and

do not use any recording apparatus. Such an operator is said to "read by sound"; his instrument is called a "sounder."

The same principle of communicating signals by making and breaking an electric circuit is used in fire and burglar alarms, hotel-annunciators, *etc.*

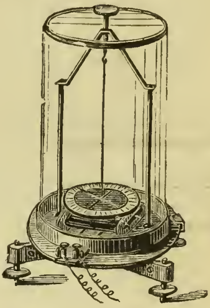

FIG. 115.

277. The Galvanometer. — We have already seen that the voltaic current has a marked effect in turning the magnetic needle from its north and south position, tending to place the needle at right angles to the direction of the current.

The galvanometer is a very delicate instrument for detecting the presence of an electric current and determining its direction and strength.

The magnetic needle is very light and suspended so as to turn easily. The wire conductor is insulated and coiled many times about the needle; the effect is thus multiplied. A glass cover protects the apparatus from dust and disturbance by air currents. The instrument is largely used. One form is represented in Fig. 115.

If the instrument shows the presence and direction of the current without measuring its strength, it is a *galvanoscope* rather than a galvanometer.

Experiment 113.—Connect an iron and a German silver wire to the binding posts of a delicate galvanometer. Twist the free ends of the wires together and heat the junction in the flame of an alcohol lamp. **The deflection of the galvanometer-needle will show that an electric current is traversing the circuit.** Cool the junction with a piece of ice. The galvanometer will show that a second current is flowing in the opposite direction.

278. Thermo-Electricity.—*If a circuit be made of two metals and one of the junctions be heated or chilled, a current of electricity is produced.*

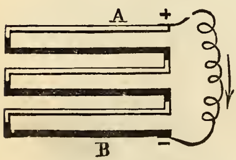

FIG. 116.

A thermo-electric pair may be made by soldering together a bar of antimony, A, and one of bismuth, B, and joining their free ends by a wire. Several such pairs may be joined to form a thermo-electric series, as shown in Fig. 116. Several such series may be joined to form *a thermo-electric pile*, the bars being separated by strips of varnished paper and compactly set in a metal frame so that only the soldered ends are open to view. The free end of the antimony bar, representing the + electrode, and the free end of the bismuth bar, representing the — electrode, are connected with binding screws, which

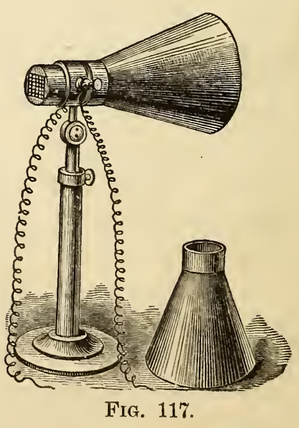
FIG. 117.

may be connected with a sensitive, short coil galvanometer (Fig. 115). The thermo-electric pile, with the addition of conical reflectors, is shown in Fig. 117.

A change of temperature at either exposed face of the pile produces a feeble current of electricity which is manifested by the movement of the needle of the galvanometer. The instrument is much used in scientific work for detecting differences in temperature, being much more sensitive than the mercury thermometer.

279. Recapitulation.—To be amplified by the pupil for review.

- CURRENT ELECTRICITY.
  - CHEMICAL ACTION.
    - VOLTAIC.
      - *Cell.*
        - One Liquid.
          - Smee's.
          - Potassium Di-chromate.
          - Leclanché.
        - Two Liquids.
          - Daniell's.
          - Callaud's.
          - Grove's.
          - Bunsen's.
        - Joined.
          - Tandem.
          - Abreast.
          - Best Method.
      - *Battery.*
        - High Internal Resistance.
        - Low Internal Resistance.
      - *Current.*
        - Direction.
        - Strength.
    - SIGN OF.
      - *Plate.*
      - *Pole.*
      - *Electrode.*
        - Anode.
        - Kathode.
    - RESISTANCE.
      - *External.*
      - *Internal.*
    - QUANTITY.
    - LOCAL ACTION.
      - *Cause.*
      - *Remedy.*
    - POLARIZATION.
      - *Cause.*
      - *Remedy.*
      - *E. M. F.*
  - EFFECTS.
    - THERMAL. *Relation to Resistance.*
    - LUMINOUS.
    - PHYSIOLGICAL.
    - CHEMICAL.
      - *Electrolysis.*
        - Anion. Kathion. — Ions.
      - *Electro-Metallurgy.*
      - *E. M. F. of Polarization.*
      - *Secondary Batteries.*
        - Faure's.
        - Brush's.
        - Uses.
        - Advantages.
    - MAGNETIC.
      - *Electro-Magnets.*
      - *Electric Telegraph.*
      - *Galvanometer.*
  - THERMO-ELECTRICITY.

EXERCISES.

1. Does dilute acid or a battery solution act upon zinc more vigorously than it does upon copper, or otherwise?

2. State three ways in which the internal resistance of a voltaic cell may be diminished. State two ways in which the strength of current of a voltaic cell or battery may be increased.

3. What is "local action" and how may it be prevented?

4. If the resistance of 18.12 yards of No. 30 copper wire be 3.02 ohms, what length of the same wire is there in a coil, the resistance of which is 22.65 ohms?

5. Given a battery of five Daniell's cells coupled in series. Each cell has an E. M. F. of 1.1 volts and an internal resistance of 2.2 ohms. The wire of the circuit has a resistance of 44 ohms. What is the strength of the current? *Ans.* $\frac{1}{10}$ ampere.

6. It is found that one Daniell's cell, however large, will not decompose acidulated water. It is also found that two Daniell's cells, however small, is sufficient for continuous electrolysis. Explain.

7. If the E. M. F. of a Daniell's cell be 1.08 volts and that of a Grove's cell 1.73 volts, the internal resistance of the former being five times as great as that of the latter and the external circuit being a stout, short copper wire, the resistance of which is so small that it may be neglected, show that the Grove's cell will give about eight times as strong a current as the Daniell's.

8. Twenty-four similar cells are arranged in four batteries of six cells, each coupled in series. These batteries are joined abreast. (*a.*) How will the E. M. F. of this battery compare with that of a single cell? (*b.*) How will its internal resistance compare with that of a single cell?

9. Given a battery of 100 Grove cells, each having an E. M. F. of 2 volts and an internal resistance of 0.25 ohms. The wire of the circuit has a resistance of 1000 ohms. Determine the strength

of the current (*a.*) when the cells are joined in series. (*b.*) When the cells are joined abreast. *Ans.* (*a.*) .195 + amperes.

10. Given the same battery as in the last exercise, the external circuit now being a short wire of only 0.001 ohm resistance. Determine the strength of the current (*a.*) when the cells are joined abreast. (*b.*) When the cells are joined in series.

Ans. (*a.*) 571.4 amperes ; (*b.*) 7.99 amperes.

11. Given a single cell like those mentioned in the last two exercises. Join its poles with a short, stout copper wire, which has a resistance of 0.001 ohm. Determine the current that it will give and see how it compares with the current of 50 such cells joined in series, as mentioned in the last exercise.

12. Short circuit the cell mentioned in the last exercise, *i. e.*, make the circuit with a wire of so little resistance that it may be dropped out of the account. Determine the strength of current. Will joining any number of cells joined in series increase this effect?

SECTION IV.

MAGNETISM.

280. Natural Magnets.—One of the most valuable iron ores is called magnetite (Fe_3O_4). Occasional specimens of magnetite will attract filings and other small pieces of iron. *Such a specimen is called a loadstone.* It is a natural magnet.

281. Artificial Magnets.—Artificial magnets are either temporary or permanent. A temporary magnet is usually made of soft iron and is called an electro-magnet. A permanent magnet is usually made of steel.

Artificial magnets have all the properties of natural magnets and are more powerful and convenient. They are, therefore, preferable for general use.

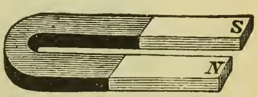

FIG. 118.

The most common forms are the *straight* or *bar* magnet and the *horseshoe* magnet. The first of these is a straight bar of iron or steel; the second is shaped like a letter U, the ends being thus brought near together, as shown in Fig. 118.

A piece of iron placed across the two poles of a horseshoe magnet is called an *armature.* We have already learned how to make artificial magnets.

282. Retentivity.—It is more difficult to get the magnetism into steel than into iron. It is also more difficult to get the magnetism out of steel than out of

iron. This power of resisting magnetization or demagnetization is called *coercive force or retentivity.* The harder the steel, the greater its retentivity. Soft wrought iron has but little retentivity.

FIG. 119.

Experiment 114.—Roll a bar magnet in iron filings. Withdraw the magnet; **the filings cling to the ends of the bar but not to the middle.**

283. Magnetic Poles.—Magnetic attraction is not evenly distributed throughout the bar.

It is greatest at or near the ends. These points of greatest attraction are called the poles of the magnet.

It is impossible, by any known means, to develop one magnetic pole without simultaneously developing another pole of opposite sign. The middle of the magnet does not attract iron and is called the *equator or neutral point.*

Experiment 115.—Bring either end of a bar magnet near the end of a piece of iron, *A B*; the iron is attracted. Bring the same end of the magnet near the middle of the iron; the iron is attracted. Bring the the same end of the magnet near the other end of the iron; the iron is attracted. Repeat the experiments with the other end of the magnet: in each case the iron is attracted.

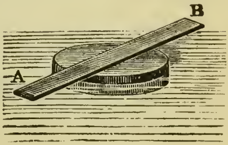

FIG. 120.

284. Attraction between a Magnet and Iron.—

Either pole of a magnet will attract ordinary iron.

Experiment 116.—Freely suspend three bar magnets, *A*, *B* and *C*, at some distance from each other. This may be done by placing each magnet in a stout paper stirrup supported by a cord or upon a board or cork floating on water. See Fig. 120. **When they have come to rest, each will lie in a north and south line.**

Magnets for this experiment may be made by magnetizing (§ 300) three stout knitting-needles. If there is any electric light apparatus in your neighborhood in charge of a good natured man, he will probably magnetize the needles for you.

Each needle may be suspended by means of a triangular piece of stiff writing-paper. Pass the needle through the paper near the lower corners; at the other corner affix by wax the end of a horse-hair. The poles may be indicated by little bits of red and of white paper, fastened by means of wax to the ends of the needles. Mark the north-seeking poles, — and the south-seeking poles, +.

285. Characteristics of Magnets.—*Magnets are chiefly characterized by the property of attracting iron and by a tendency to assume a particular direction of position when freely suspended.*

Experiment 117.—(*a.*) Take magnet A of Experiment 116 from its support, and bring its + end near the end of B or C. Notice the attraction.

(*b.*) Bring the + end of A near the + end of B or C. Notice the repulsion.

(*c.*) Bring the – end of A near the – end of B or C. Notice the repulsion.

(*d.*) Bring the – end of A near the + end of B or C. Notice the attraction.

(*e.*) From experiment (*a*) we learned that the – ends of B and C were each attracted by the + end of A. Bring the – end of B near the – end of C. Notice that they now repel.

(*f.*) From experiment (*b*) we learned that the + ends of B and C were each repelled by the + end of A. Bring the + end of B near the + end of C. Notice that they now repel.

(*g.*) In similar manner show that the + end of B will attract the – end of C; that the – end of B will attract the + end of C.

Record the results of your experiments in tabular form, thus:

(*a.*) + attracts –.	(*b.*) + repels +.
(*d.*) – attracts +.	(*c.*) – repels –.
etc.	*etc.*

Experiment 118.—Vary the last experiment by pasting a paper image of a man at the + pole of each of the magnetized needles and a paper image of a woman at the – end of each. Notice that the men are unfriendly and will not approach each other; that the women turn from each other, but that the man and the woman are attracted toward each other.

Experiment 119.—Magnetize a number of fine sewing-needles by drawing the + end of a bar magnet three or four times from the eye to the point of each. Cut several small corks into slices about an eighth of an inch thick. Through each cork disc, push

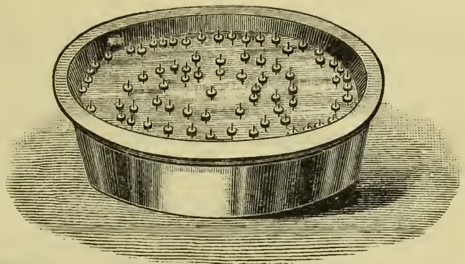

FIG. 121.

a needle up to its eye and place them in a round dish of water. These little magnets have their like poles presented to each other and they mutually repel. Bring the bar magnet, with its + end downwards, over the needles; they will be driven to the sides. Similarly, bring the — end over them; they will be attracted toward the centre.

286. Laws of Magnets. — (1.) *Every magnet has two similar poles; like poles repel each other; unlike poles attract each other.*

(2.) *Magnetic force, like other forms of attraction and repulsion, varies inversely as the square of the distance.*

Experiment 120.—Dip one of the magnetized knitting-needles into iron filings, as in Experiment 114. Notice that filings cling to the ends, near the paper discs but that none cling to the middle. Now break the needle in the middle and dip each piece

into iron filings. Notice that the unmarked ends, which were at the middle of the unbroken magnet, now attract iron filings as well as do the marked ends. **Poles have been developed in parts of the needle that previously showed no magnetic attraction.**

287. Effect of Breaking a Magnet.—If a magnet be broken, each piece becomes a magnet with two poles and an equator of its own. These pieces may be repeatedly subdivided and each fragment will be a perfect magnet.

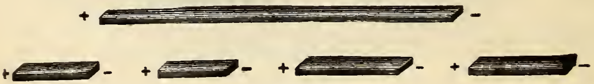

FIG. 122.

It is probable that every molecule has its poles or is polarized and that, could one be isolated, it would be a perfect magnet.

288. Magnetized, Magnetic and Diamagnetic Substances.—A *magnetized* body is one that can be made to repel a pole of a freely suspended magnet.

Substances that are attracted by a magnet are called *magnetic; e. g.*, iron, steel and nickel.

Substances that are repelled by a magnet are called *diamagnetic; e. g.*, bismuth, antimony and arsenic.

Of these, iron is by far the most magnetic, while bismuth is the most diamagnetic.

Experiment 121.—Wrap a bar magnet in a piece of cloth. With it, attract and repel the poles of a suspended magnet.

Experiment 122.—Repeat the last experiment, holding a slate or sheet of zinc between the two magnets.

Experiment 123.—Put one piece of the broken magnet into a bottle; cork the bottle tightly. With it, attract and repel the poles of a suspended magnet.

289. Magnetic Screens.—*Nothing but a magnetic body can cut off the action of a magnet.*

Experiment 124.—Place a piece of card-board or rough drawing paper over a good bar magnet. Sprinkle iron filings upon the card-board and tap it lightly. The iron particles will move and arrange themselves in well defined curved lines. See Fig. 123.

290. Magnetic Field.—A magnet seems to be surrounded by an atmosphere of magnetic influence called *the magnetie field.* The magnetic curves, shown in the above experiments, show the direction of *the lines*

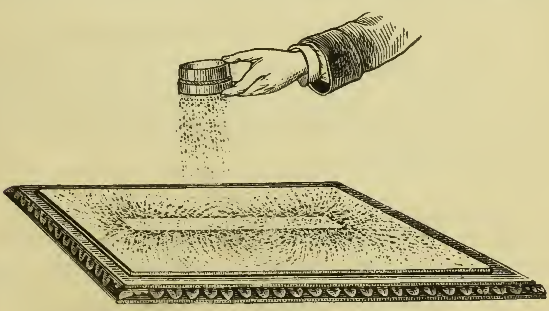

Fig. 123.

of magnetic force. If a small magnetic needle be suspended over the card-board, its length will tend to lie in the direction of the lines of magnetic force as mapped out by the iron filings.

The "magnetic curves," formed in the last experiment, are very interesting and instructive. The filings in any one of these curves are temporary magnets with adjoining poles opposite and therefore attracting. By using two bar magnets placed side by side, first, with like poles near each other, and, secondly, with unlike poles near each other, their combined effect on the iron filings may be easily observed.

Experiment 125.—Rub *one end* of a steel pen against the end of a magnet. Dip the pen into iron filings and notice that the newly made magnet has a pole at *each end*. Determine the sign of each of these poles, as indicated in Experiment 116.

291. Magnetization by Contact.—*A bar of iron or steel may be magnetized by rubbing it against a magnet.*

Pure or soft iron is easily magnetized but quickly loses its magnetism when the magnetizing influence is removed. Hardened steel is magnetized with more difficulty but retains its magnetism after the removal of the magnetizing influence.

Experiment 126.—Move the point of an unmagnetized steel pen to and fro very near one end of a magnet but without touching it to the magnet. Dip the pen into iron filings and determine

Fig. 124.

whether or not it has been magnetized. If it has, determine the sign of each pole, as in the last experiment and notice whether

the point of the pen is of the same polarity as the end of the magnet near which it was moved.

Experiment 127.—Bring a short bar of soft iron, *I*, very near a strong bar magnet, *M*, end to end, as shown in the figure. Sprinkle iron filings over the end of the iron bar and they will cling as they would to a magnet. **The iron bar is a magnet, while it remains in this position.**

292. Magnetic Induction.—If the end of a bar of soft iron be brought near one of the poles of a strong magnet, *the iron becomes, for the time being, a magnet.* The poles of the temporary magnet will be opposite to those of the permanent magnet, *i. e.*, if the + or positive pole of the magnet be presented to the iron bar, it will develop a — or negative pole in the nearest end of the iron bar and a + pole at the further end. Bring the iron bar nearer the magnet and this effect will be increased.

Actual contact is not necessary, but when the iron and the magnet touch, the magnetizing force is the greatest. If a steel bar be used instead of an iron bar, it will be permanently instead of temporarily magnetized.

The iron or the steel is induced to become a magnet by the influence of the magnet used. It is said to be magnetized by induction.

Experiment 128.—Bring a soft iron ring to the end of a magnet. It will be supported. Bring a second ring into contact with the first ring and it will be supported. In this way quite a number of rings may be supported, each ring being magnetized by the bar or ring magnet above it. Of course, the attractive force

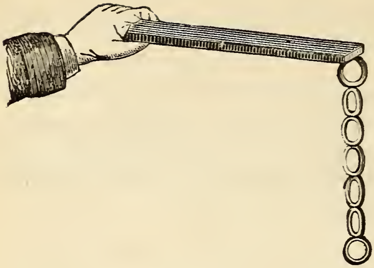

FIG. 125.

is continually weakening from the first to the last ring.

Now support the upper ring upon your finger and remove the magnet. Each ring ceases to be a magnet and the chain is broken into its separate links.

Experiment 129.—Vary the last experiment by using, instead of the rings,

1. Soft iron nails.
2. Steel sewing-needles.

See if there is any difference in the results.

Experiment 130.—Suspend an iron key from the positive end of a bar magnet. A second bar magnet of about the same power, with its poles opposite, is moved along the first magnet. **When the – end of the second magnet comes over the key, the key drops.**

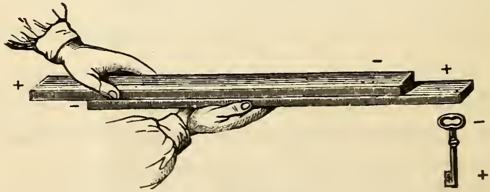

FIG. 126.

The first magnet tends to induce a – pole at the upper end of the key. The second magnet tends to induce a + pole at the same point. Hence the effect of each magnet neutralizes that of the other.

Experiment 131.—Magnetize a piece of watch spring about six inches long (easily obtainable at the watch repairer's) by drawing it several times between the thumb and the end of a magnet. Dip it into iron filings Lift it carefully with its load. Bring the poles of the spring magnet together, bending the magnet into a ring. **The magnet drops its load.**

293. Induction Precedes Attraction.—We now see why a magnet attracts ordinary iron; it first magnetizes it and then attracts it. The attraction between unlike poles is greater than the repulsion between like poles because of the smaller distance between them. Compare § 225.

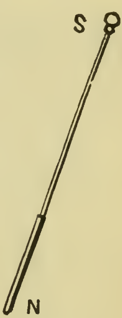

Fig. 127.

Experiment 132.—Test a common fire-poker for magnetism by bringing a small magnetic needle near its ends and seeing whether the poker *repels* either pole of the compass needle or whether the two ends of the poker attract *different* poles of the needle.

Experiment 133.—If the poker is not slightly magnetic, place it with its upper end sloping toward the south so as to make an angle of a little less than half a right angle. In other words, place it in the position assumed by the dipping needle. (§ 295.) While the poker is in this position, strike it a few blows with a wooden block or mallet. Test it again for magnetism.

294. The Earth is a Magnet.—The earth acts like a huge magnet in determining the direction of compass and dipping needles. Its inductive influence, as shown in the last experiment, strengthens the belief

that it has such action. In short, many facts seem to teach that *the earth is a great magnet with magnetic poles near its geographical poles.*

Experiment 134.—By means of a fine wire fork, gently lay one of the magnetized sewing-needles of Experiment 119 on the surface of water. It will float without any cork or similar support and will assume a north and south position. It may be considered the needle of a small compass.

295. Magnetic Needles.—*A small bar magnet suspended in such a manner as to allow it to assume its chosen position is a magnetic needle.*

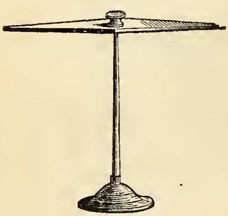

FIG. 128.

(*a.*) If it be free to move in a horizontal plane, it is a horizontal needle; *e. g.*, the mariner's or the surveyor's compass (Fig. 128). It will come to rest pointing nearly north and south. If the magnet be free to move in a vertical plane it constitutes a vertical or dipping needle (Fig. 130).

(*b.*) Make a horizontal needle of a piece of watch spring about six inches long and straightened by drawing it between thumb and finger. Heat the needle to redness in a flame and bend it double. Bend the ends back into a line with each other, as shown in Fig. 129. Magnetize each end separately and oppositely. Wind a waxed thread around the short bend at the middle to form a socket and balance the needle upon the point of a sewing-needle thrust into a cork for support. A little filing, clipping with shears or loading with wax may be necessary to make it balance.

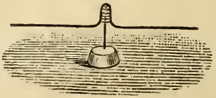

FIG. 129.

(*c*.) Make a dipping needle by thrusting a knitting-needle through a cork so that the cork shall be at the middle of the needle. Thrust through the cork, at right angles to the knitting-needle, half a knitting-needle, or a sewing-needle, for an axis. Support the ends of the axis upon the edges of two glass goblets or other convenient objects (see Fig. 130). Push the knitting-needle through the cork so that it will balance upon the axis like a scale-beam. Magnetize the knitting-needle and notice the *dip*.

(*d*.) A magnetized sewing-needle, suspended near its middle (at its centre of gravity) by a fine thread or hair or an untwisted fibre will serve as a dipping needle. It should first be suspended so as to hang horizontal and magnetized afterward. A simple form of dipping needle is represented in Fig. 130.

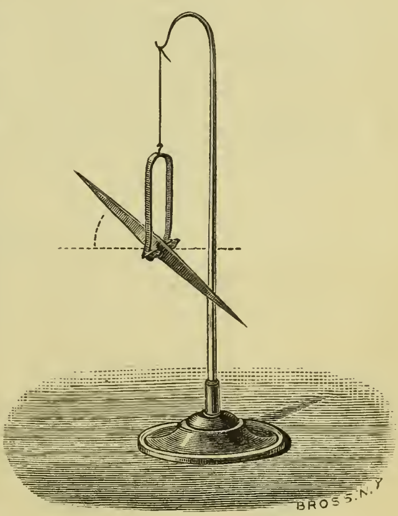

FIG. 130.

Experiment 135.—Measure the angle that your dipping needle makes with the surface of quiet water. The angle in question is indicated by the dotted arc of Fig. 130.

296. Inclination or Dip.—*The angle that a dipping needle makes with a horizontal line is called its inclination or dip.*

At the magnetic poles, the inclination is 90°; at the magnetic equator, there is no inclination. The inclination at any given place is not greatly different from the latitude of that place.

Experiment 136.—Set two stakes so that a string joining them will point toward the North Star. The string will run north and south or nearly enough so for our purpose. Place a long magnet suspended as a needle under or over the string. Looking downward at the magnet and the string, it will probably be found that the needle and the string do not point in the same direction.

The North Star may be easily found any evening in the direction indicated by "The Pointers" of the well known constellation, "The Great Dipper." "The Pointers" are the two stars marked by the Greek letters α and β in the diagram below.

In winter, the dipper is seen in this position, east or north-east of the North Star.

In summer evenings, the dipper is seen in this position, west or north-west of the North Star.

297. Declination or Variation. — The magnetic needle, at most places, does not lie in an exact north and south line.

The angle which the needle makes with the geographical meridian is its declination or variation.

Experiment 137.—Send a current of electricity from the small cell, mentioned in Experiment 84 through its wire. Pour half a teaspoonful of iron filings upon a sheet of paper and bring the wire conductor of the cell into contact with the filings. Notice that the filings cling to the wire as though it were a magnet. Break the circuit and notice that the filings fall from the wire.

298. Electro-Magnets.—From the last experiment, we see that while the wire conductor was carrying an electric current it had the properties of a magnet. We have already seen that under similar circumstances, the conductor deflects a magnetic needle as if it were itself a magnet. In fact, such a conductor is a temporary magnet. The magnetic effect is much increased if a considerable length of the conductor be made of cotton covered (insulated) wire and wound into a coil, as shown in Fig. 131. Such a coil is a magnet with a + pole at one end and a — pole at the other. It has an easily perceptible magnetic field. If a soft iron rod or core be introduced into the coil, it enters the magnetic field of the coil or helix and becomes a magnet.

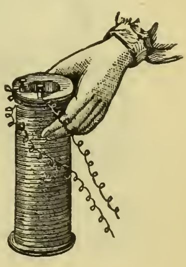

Fig. 131.

This combination of coil and core constitutes an electro-magnet and is more powerfully magnetic than the coil alone.

An electro-magnet is a bar of iron surrounded by a coil of insulated wire carrying a current of electricity.

It may be made more powerful than any permanent magnet but loses its power as soon as the current ceases to flow through its coil. The fact that *the magnetism of this apparatus is under control* adapts it to many important uses, such as electric bells and telegraphic instruments.

299. Forms of Electro-Magnets.—The bar of § 275, *a*, and the ring of Fig. 113, with their helices, are electro-magnets. The electro-magnet more often has the horse-shoe form shown in Fig. 132, so that the attraction of both poles may act upon the same body at the same time. The middle of the bent bar is bare, the direction of the windings on the ends being such that, were the bar straightened, the current would move in the same direction round every part.

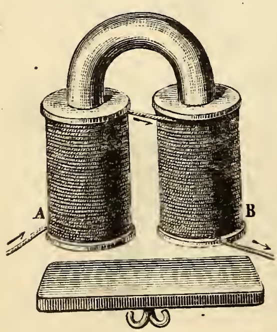

FIG. 132.

More frequently, the two helices, *A* and *B*, have separate cores which are joined by a third straight piece into which the ends of the cores are screwed. An armature is often placed across

the two poles of the magnet, as shown in the figure. Electro-magnets have been made capable of supporting several tons.

(*a.*) When the circuit is broken and the current thus interrupted, the iron is generally not *wholly* demagnetized. The small magnetism remaining is called *residual magnetism.* The residual magnetism seems to vary with the hardness and impurity of the iron. The cores of electro-magnets for some purposes are made of the softest and purest iron attainable.

300. Making Permanent Magnets.—A steel bar may be permanently magnetized by drawing it, from its centre, in one direction over one pole of a powerful magnet and then, from its centre, in the opposite direction over the other pole, and repeating the process a few times. (Fig. 133.)

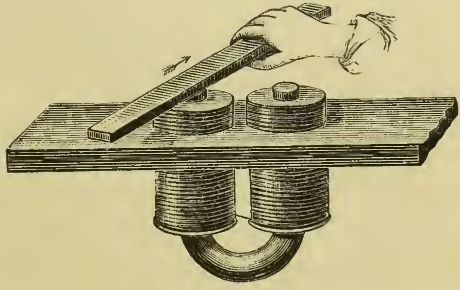

Fig. 133.

A bar of steel placed within a helix through which a strong current is passing, will be permanently magnetized.

A steel bar may be magnetized by striking it on end with a wooden mallet while it is held in the direction assumed by the dipping needle.

301. Relation of Magnetism to Energy. — A magnet is a reservoir of potential energy. This energy is due to the expenditure, at some time, of a definite amount of energy of some kind. By virtue of its potential energy, it can do a definite amount of work *and no more.* For instance, it may attract a certain amount of iron. When thus fully loaded, the magnet has done its full work and can do no more. When the iron is torn from the magnet, more energy is expended and the magnet thus endowed again with potential energy. A magnet has not an inexhaustible supply of energy, as some have supposed.

302. Recapitulation.—To be amplified by the pupil for review.

MAGNETISM.

- MAGNETS.
  - NATURAL.
  - ARTIFICIAL..
    - *Permanent*.... ..
      - Forms.
      - How Made.
    - *Temporary or Electro-Magnets.*
      - Definition.
      - Advantages.
      - Forms.
      - Residual Magnetism.
  - MOLECULAR.
  - POLES.
  - CHARACTERISTICS.
  - LAWS.
  - RELATION TO
    - *Magnetic*......... Substances.
    - *Diamagnetic* .... Substances.
- RETENTIVITY.
- MAGNETIC SCREENS.
- MAGNETIZATION.
  - BY CONTACT.
  - BY INDUCTION.......
    - *Magnetic Curves.*
    - *Lines of Force.*
    - *Precedes Attraction.*
- TERRESTRIAL.....
  - POLES.
  - MAGNETIC NEEDLES.
    - *Compass.*
    - *Dipping.*
  - DECLINATION.
  - DIP.
- RELATION TO ENERGY.

EXERCISES.

1. State the first law of magnets and tell why you believe it to be true.

2. When you break a bar magnet have you two *parts* of a magnet?

3. What is meant by retentivity? What other name has the same thing?

4. Give good reasons for believing that the earth is a magnet.

5. Mention three magnetic substances.

6. How can you obtain a magnet with a single pole?

7. A dozen steel sewing-needles are hung in a bunch by threads passed through their eyes. How will they behave when hung over the pole of a strong magnet?

8. Devise an experiment to show how to cut off the influence of a magnet from a piece of iron that is not far distant.

9. If one should carry a dipping needle from the north magnetic pole of the earth to the south magnetic pole, how would the needle change its position during the journey?

10. How can I magnetize an iron bar without using a current of electricity or a steel or iron magnet?

11. What is the difference between magnets and magnetized matter?

12. Six sewing needles are magnetized and thrust vertically through six little floats of cork. They are placed in a vessel of water, with the + pole of each needle magnet pointing upward. What will be the effect of holding the — pole of a larger magnet over them?

SECTION V.

INDUCED ELECTRICITY.

303. Induced Currents.—From our study of frictional electricity and magnetism, we are familiar with the term *induction*, by which we understand the influence that an electrified body exerts upon a neighboring unelectrified body or that a magnetized body exerts upon a neighboring magnetic but unmagnetized body. In 1831, Faraday discovered an analogous class of phenomena which we are now about to consider.

An induced current is a current produced in a conductor by the influence of a neighboring current or magnet.

A current used to produce such an effect is called an inducing current.

304. Inductive Effect of Closing or Breaking a Circuit.—In Fig. 134, B represents a double coil made as follows: On a hollow cylinder of wood or cardboard is wound several layers of stout copper wire, insulated by being covered with silk or cotton. The two ends of this wire, which constitutes the *primary coil*, are seen dipping into the cups $g\ g'$.

Upon this coil and carefully insulated from it, is wound a much greater length of finer, insulated copper wire. The two ends of this wire, which constitutes the *secondary coil*, are seen connecting with a delicate, long coil galvanometer, G. Remember that there is no elec-

trical connection between the two coils. Wires from the two plates of a voltaic cell, P, dip into mercury in the cups $g\,g'$, thus closing an inducing circuit through the primary coil of B.

While this circuit is closed, the galvanometer is at rest, showing that no current is passing through the secondary coil. By lifting one of the wires from one of the cups, the inducing current is interrupted. At this instant the

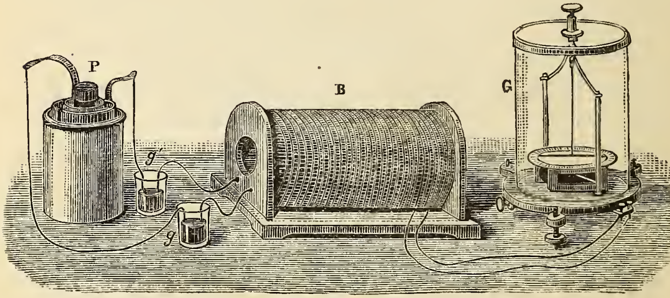

FIG. 134.

galvanometer needle is deflected as by a sudden impulse, which immediately passes away. This movement of the galvanometer needle shows the existence of a momentary induced current in the secondary coil. If the wire just removed from the cup be replaced and the inducing current thus re-established, the galvanometer needle will be momentarily turned in the direction opposite to that in which it was previously turned.

When a current begins to flow through the primary coil, it induces a current in the secondary coil.

When it ceases to flow through the primary coil, a current flowing in the opposite direction is induced in the secondary coil.

Both induced currents are merely momentary in duration.

305. The Extra Current.—When a circuit is made or broken, each convolution of a coil placed in the circuit acts inductively upon the other convolutions of the coil as if they were portions of two unconnected circuits.

This action is called the induction of a current upon itself; the current thus produced is called the extra current.

(*a.*) When the circuit is made, the extra current is inverse or opposite in direction to the primary current and acts against it. The extra current at the breaking of the circuit is direct and *adds its effect to that of the primary current.*

(*b.*) Hence, a spark is seen on breaking but not on making contact. Increasing the number of coils or convolutions in the circuit will increase the brilliancy of the spark. If the coil has an iron core (electro-magnet) the effect is especially marked.

306. Ruhmkorff's Coil.—*The induction coil is a contrivance for producing induced currents in a secondary coil by closing and opening, in rapid succession, the circuit of a current in the primary coil.*

The essential parts are described in § 304. In the complete instrument, the axis of the coils is a bundle of soft iron wires. The primary circuit is rapidly broken

and closed by an automatic interrupter, shown at the left hand end of the coil in Fig. 135.

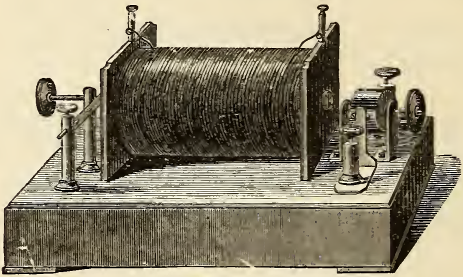

FIG. 135.

The primary coil is placed in the circuit of a voltaic battery. The current induced in the secondary coil is of high potential.

307. Currents Induced by Change of Distance.—The primary coil may be made movable.

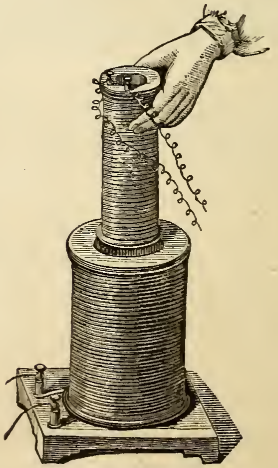

FIG. 136.

When the primary coil, bearing a current, is brought near or thrust into the secondary coil, a current is induced in the latter.

When the coils are separated, a current flowing in the opposite direction is induced in the secondary coil.

The induced currents flow while a change of distance is varying the inductive effect of the primary current.

Removing the primary coil to an infinite distance would be equivalent to breaking its circuit, as in § 304.

308. Magneto-Electric Currents. — We have already noticed that there is an intimate relation be-

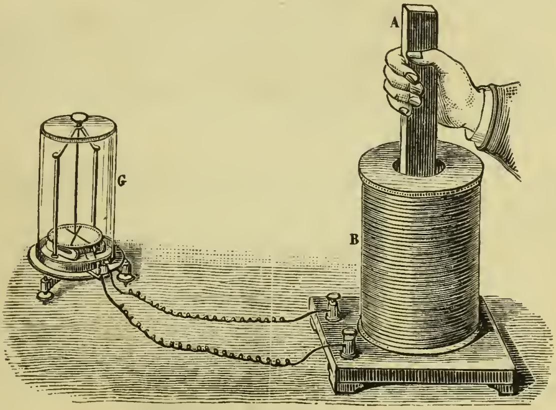

FIG. 137.

tween electric and magnetic action. We have seen that an electric current may develop magnetism and have, perhaps, wondered if magnetism may be made to develop an electric current. Faraday found that electricity may be thus produced ; the results of this discovery have already become of incalculable commercial importance. If, instead of the primary coil bearing the inducing current, a bar magnet be used, as shown in Fig. 137, the effects produced will be like those stated in the last paragraph.

When the magnet is thrust into the interior of the coil, an induced current will flow while the motion of the magnet continues.

When the magnet is stationary, the current ceases to flow and the needle of the galvanometer gradually comes to rest.

When the magnet is withdrawn, an induced current flows in the opposite direction.

Of course, it makes no difference whether the magnet be moved toward the coil or the coil be moved toward the magnet. The more rapid the motion, the stronger will be the induced currents.

309. The Inductive Action of a Temporary Magnet.—If within the coil a soft iron bar (or still better, a bundle of straight, soft, iron wires) be placed,

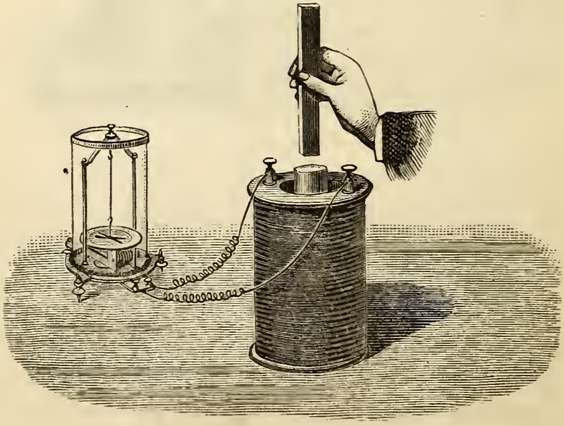

FIG. 138.

as shown in Fig. 138, the induced current may be more effectively produced by bringing one end of a permanent magnet near the end of the soft iron. In this case the induced currents are due to the varying magnetism of the soft iron, this magnetism being due, in turn, to the inductive influence of the permanent magnet (§ 292).

When the intensity of the magnetism of a bar of iron is increased or diminished, currents are induced in the neighboring coil.

Similar effects may be produced by moving one pole of the magnet across the face of the coil from end to end.

310. The Wheel Armature. — Imagine the soft iron bar in the helix of Fig. 138, to be grooved and several times as long as the helix through which it passes. Imagine the ends of this bar to be brought together so as to form a complete iron ring carrying one helix. If the number of helices upon the ring be increased to eight, we shall have the wheel armature shown in Fig. 139.

If the pole of a magnet be passed around the face of this wheel, it will pass eight coils of wire and induce a current of electricity as it approaches each coil and an opposite current as it leaves each coil, thus inducing sixteen currents for each revolution. Of course, it makes no difference whether the magnet be permanent or temporary, *whether the pole of the magnet moves by the coil or the coil passes by the pole of the magnet.* Then, if the magnet be fixed and the wheel turns upon

its axis in such a way as to carry its coils across the ends of the magnets, we shall be inducing sixteen currents of electricity for each revolution of the wheel. This is what happens in the operation of a dynamo-electric machine.

When a closed circuit conductor moves in a magnetic field so as to cut across the lines of magnetic force (§ 290), *an induced current of*

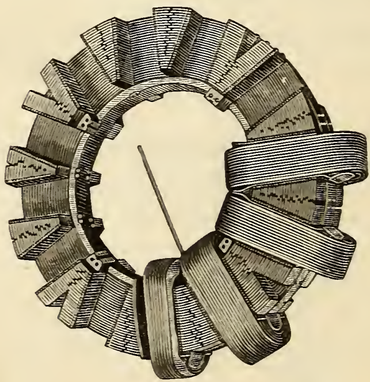

FIG. 139.

electricity flows through the conductor in one direction while the conductor is approaching the point of greatest magnetic intensity and in the opposite direction while the conductor is moving away from such point of maximum intensity.

The varying magnetic intensity of the iron core of each moving coil increases this effect, as explained in

§ 309. Of course, the number of coils on the armature may be more or less than eight, or the armature may be of a form almost wholly different from that just described but, in every case, the principle of its action is as above stated.

311. Dynamo-Electric Machines.—In the Brush dynamo-electric machine, represented in Fig. 140, a shaft runs through the machine from end to end, carrying a pulley, *P*, at one end, a commutator, *c*, at the other and a wheel armature, *R*, at the middle. The armature, *R*, carries eight or more helices of insulated wire, *H H*. As the shaft is turned by the belt acting upon *P*, *R* and *c* are turned with it. As *R* turns around, it carries the eight coils, *H H*, rapidly across the poles of the four powerful field magnets, *M M*.

As each coil passes each pole, it necessarily traverses the magnetic field and cuts across the lines of magnetic force; consequently, currents are induced in the coil.

These currents are carried on insulated wires to the commutator rings, *c c*, where they are united in such a way as all to flow in the same direction, forming a continuous current. The electricity is taken from *c c*, by the four or more copper plates, *i i*, technically called "brushes," and then carried down the flexible copper strips, *s s*, then passed through all the insulated wire of the electro-magnets *M M*, and, finally, to the + binding post.

Thence the current passes by a wire to the external

circuit, *e. g.*, to an arc lamp (Fig. 142) and from this to a second lamp, and so on through all of the lamps of the circuit and from the last lamp back to the — binding post of the dynamo-electric machine, thus making the circuit complete. Sixty or more arc lamps in series may be worked by one of these machines.

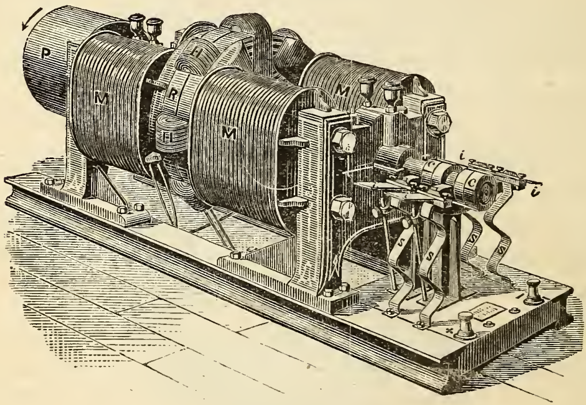

Fig. 140.

Dynamo-electric machines are being rapidly introduced for purposes of electric lighting, electro-plating, motive power, telegraphy, *etc.* They are made in various forms, but the principle underlying the action of them all is the same as that stated in the last paragraph. After mastering the action of one dynamo-electric machine, the pupil will have little trouble in understanding the action of any other that he may have a chance to examine. Dynamo-electric machines are often called "dyna-

mos." A small dynamo, with hand power, suitable for school use, may be had for $30 or more.

(*a.*) If permanent magnets are used instead of electro-magnets, the machine is called a *magneto-electric* instead of a dynamo-electric machine.

(*b.*) If instead of expending mechanical energy to turn the shaft of the dynamo and thus produce an electric current, we pass a strong current of electricity through the dynamo, the shaft of the dynamo will be turned in the opposite direction and may be made to drive ordinary machinery as an *electric motor.* In the former case, we convert mechanical energy into electric energy; in the latter case, we convert electric energy into mechanical energy.

THE SWAN ELECTRIC LAMP.

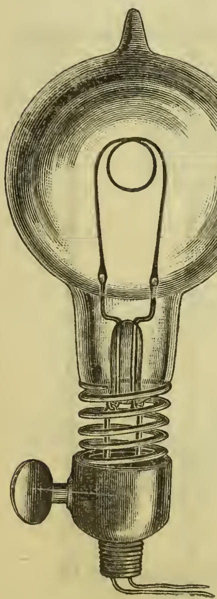

FIG. 141.

312. Incandescent Electric Lamps. — When a conductor is heated to incandescence by the passage of a current, we have an illustration of the fundamental principle of incandescent electric lighting. To prevent the fusion of the conductor, a carbon filament, about the size of a horse-hair, is used—carbon never having been melted.

To prevent the combustion of the carbon filament, it is enclosed in a glass globe containing either a high vacuum or only some inert gas, incapable

of acting chemically upon the carbon at even the high temperature to which it is to be subjected.

The filament is carbonized in different ways and given different shapes by different inventors. Fig. 141 represents the Swan incandescent lamp and is half the actual size.

THE BRUSH ELECTRIC LAMP.

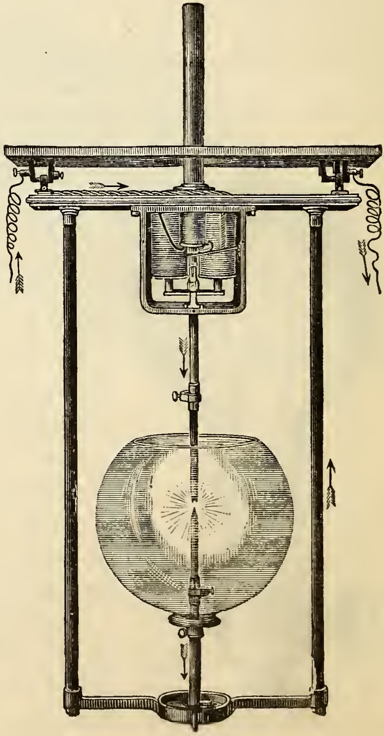

FIG. 142.

313. The Voltaic Arc.—The most brilliant luminous effect of current electricity is the arc lamp. (Fig. 142.) This consists essentially of two pointed bars of hard carbon, generally copper coated (Experiment 112), placed end to end in the circuit of a very powerful current. If the ends of the carbons be separated a short distance while the current is passing, the carbon points become incandescent and the current will not be interrupted.

When the carbons are thus separated, their tips glow with a brilliancy which exceeds that of any other light under human control, while the temperature of the intervening arc is unequaled by any other source of artificial heat.

The mechanism shown in the upper part of Fig. 142, is for the purpose of automatically separating the carbons and "feeding" them together as they are burned away at their tips and for the purpose of cutting the lamp out of the circuit in case of any irregularity or accident. Such lamps of from one to two thousand candle power and requiring an expenditure, at the dynamo, of about one horse-power *per* lamp, are now quite common. Lamps of a hundred thousand candle power have been made. The current may be furnished by a battery of forty or more Grove's cells but, for economical reasons, it is almost universally supplied by a dynamo-electric machine.

314. The Telephonic Current.—An electric current may be induced in a coil of insulated wire surrounding a bar magnet by the approach and withdrawal of a disc of soft iron. The disc *a* (Fig. 143), is magnetized by the inductive influence of the magnet *m* (§ 292). The disc, thus magnetized, reacts upon the magnet, *m*, and changes the distribution of magnetism therein. By varying the dis-

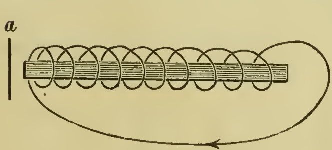

Fig. 143.

tance between a and m, the successive changes in the distribution of the magnetism of m induce to-and-fro currents in the surrounding coil (§ 309). When a approaches m, a current flows in one direction; when it recedes, the current flows in the opposite direction.

315. The Telephonic Circuit.—If the wire surrounding the magnet mentioned in the last paragraph be continued to a distance and then wound around a second bar magnet, as shown in Fig. 144, the currents

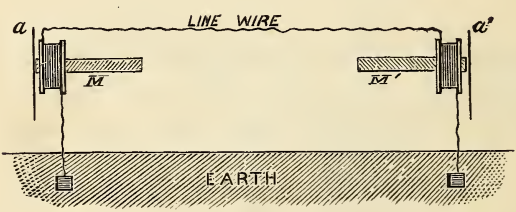

FIG. 144.

induced at M would affect the magnetism of the bar at M' (§ 298) or the intensity of its attraction for the neighboring disc a'.

A vibratory motion in the disc a would induce electric currents at M; these currents, when transmitted to M', perhaps several miles distant, would affect the magnetism of the bar there.

When the current generated at M flows in such a direction as to reinforce the magnet at M', the latter attracts a' more strongly than it did before. When the current flows in the opposite direction, it weakens the magnetism of M', which then attracts a' less. The disc,

therefore, flies back. Thus, the vibrations of a' are like those of a.

(a.) We have here the principle of the telephone, so far as electric action is involved. Further consideration of this instrument must be deferred until we have learned more concerning sound. (See § 335.)

316. Recapitulation.—To be amplified by the pupil for review.

HIGH POTENTIAL ELECTRICITY INDUCED BY

- CLOSING.. / BREAKING — PRIMARY CIRCUIT.
  - *Primary...* / *Secondary* . / *Ruhmkorff* — Coils.
- CHANGE OF DISTANCE OF PRIMARY CIRCUIT.
- MAGNETS.
  - PERMANENT.
    - *Telephones.*
    - *Magneto-Electric Machines.*
  - TEMPORARY.
    - *Wheel Armature.*
    - *Dynamo - Electric Machines which are largely used for.............*
      - Electro-Plating.
      - Incandescent Electric Lighting.
      - Arc Electric Lighting.
      - Charging Storage Batteries.

EXERCISES.

1. A manufacturer has surplus power at his mill. How can he utilize this power to illuminate his residence, two miles distant?

2. The ends of a coil of fine insulated wire are connected with the terminals of a long coil galvanometer. A steel bar magnet is slowly pushed into the hollow of the coil and then suddenly jerked out. What actions will be observed in the needle of the galvanometer?

3. Experience showed that the actual cost of 71 arc electric lights of 2000 nominal candle power each, was as follows:

Consumption of carbons per hour.........	$0.89
Power used for dynamo-electric machine..	.65
Interest on cost of machines......	.30
Attendance, oil, wear and tear, *etc*.........	.36
Total cost *per* hour..................	$2.20

These electric lamps displaced 578 gas burners. Ignoring all considerations except that of dollars and cents, reckoning the consumption of gas at six cubic feet *per* hour for each burner and the cost of gas at $2 *per* 1000 cubic feet, (*a.*) which light is the cheaper? (*b.*) What is the difference in cost *per* hour? (*c.*) What is the difference in cost *per* year, the lights being burned 3000 hours *per* year?

REVIEW QUESTIONS.

1. (*a.*) Describe the barometer. (*b.*) Describe the lifting-pump.

2. What class of lever is represented by a common wheelbarrow?

3. What simple machine is represented by a carpenter's chisel?

4. What three elements of work measure are involved in the term "horse-power"?

5. From a bottle, cork and glass tubing, construct the apparatus shown in Fig. 145. Make all joints air-tight. Place *a* in water and suck at *b* until a jet is formed at *j*. Explain the action of the apparatus.

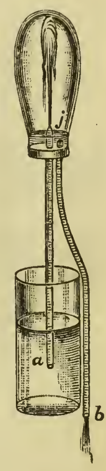

FIG. 145.

6. (*a.*) What are the essentials of a good lightning rod? (*b.*) What is an anion?

7. A circular copper dish is joined to the zinc plate of a small battery. Acidulated water is poured into the dish. A wire from the carbon plate of the battery dips into the middle of the liquid. A few scraps of cork are thrown in to render visible any motion of the liquid. The — pole of a strong bar magnet is held above the dish. What is the effect?

8. What phenomenon resulted from the greatest difference of electric potential that *you* ever knew anything about?

9. What property of matter is illustrated by the fact that when a stone is thrown into water, it will displace its own bulk of water?

10. What is the difference between a liquid and a gas? Which is a fluid?

11. Describe the three classes of levers.

12. The E. M. F. of a dynamo-electric machine furnishing current for 16 arc electric lamps, is 839 volts. The lamps are placed in series, each one having a resistance of 4.56 ohms. The internal resistance of the dynamo is 10.54 ohms. The line wire has a resistance of 0.4 ohms. What is the strength of the current?

13. When I rub together two bodies, which is developed sooner, + or — electricity?

14. How does the shape of a conductor affect electric density?

15. (*a.*) What is Ohm's law? (*b.*) What is an ohm?

16. A ball has been freely falling for five seconds. (*a.*) What is its velocity? (*b.*) How far has it fallen?

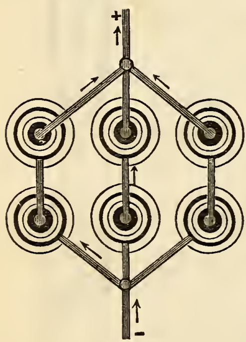

FIG. 146.

17. How can you fire gunpowder with a voltaic current?

18. Find the current (in amperes) given by six Grove cells, joined as shown in Fig. 146, assuming each cell to have an E. M. F. of 2 volts and an internal resistance of 0.30 ohms, the external resistance being 10 ohms.

19. A strip of paper that has been rubbed with india-rubber is brought near a glass rod that has been rubbed with silk. What happens?

20. Was the paper strip mentioned in the last question charged with + or — electricity?

21. If you rub with flannel a stick of sealing-wax held in the hand, it becomes electrified. If similarly you rub a rod of brass it does not become electrified. Explain the difference.

22. If the E. M. F. of a current from an Edison dynamo be 54 volts and the resistance of the filament of an Edison incandescent electric lamp be 90 ohms, what will the current measure in amperes? (Disregard the resistance of the line wire.)

23. If the carbon filament of a Swan incandescent electric lamp has a resistance of 40 ohms and a Brush storage battery sends through it a current of 1.25 amperes, what is the E. M. F. of the battery? (Disregard the resistance of the line wire.)

CHAPTER VII.

SOUND.

SECTION I.

NATURE, REFRACTION AND REFLECTION OF SOUND.

317. Definition of Sound.—*Sound is the mode of motion that is capable of affecting the auditory nerve.*

(*a.*) The word sound is used in two different senses. It is often used to designate a *sensation* caused by waves of air beating upon the organ of hearing; it is also used to designate these aërial waves themselves. If every living creature were deaf, there could be no sound in the former sense, while in the latter sense the sound would exist but would be unheard. The definition above considers sound in the latter or physical sense only.

318. Undulations.—In beginning the study of acoustics, it is very important to acquire a clear idea of the nature of undulatory motion. When a person sees waves approaching the shore of a lake or ocean, there arises the idea of an *onward* movement of great masses of water. But, if the observer give his attention to a piece of wood floating upon the water, he will notice that it merely rises and falls without approaching the

shore. He may thus be enabled to correct his erroneous idea of the onward motion of the water.

Again, he may stand beside a field of ripening grain and, as the breezes blow, he will see a series of waves pass before him. But, if he observe carefully and reflect, he will see clearly that there is no movement of matter from one side of the field to the other; the grain-ladened stalks merely bow and raise their heads. Most persons are familiar with similar wave movements in ropes, chains and carpets.

Each particle of matter has a motion, but that motion is vibratory, not progressive. The onward movement is that of the wave but not of the particles which compose the wave.

It is a familiar fact that a wave may transmit energy.

(*a.*) The motion of the wave must be clearly distinguished from the motion of particles which constitute the wave. The wave may travel to a great distance; the journey of the individual particle is very limited.

Experiment 138.—Suspend a pith ball by a thread so that it shall hang lightly against one prong of a tuning fork. When the fork is sounded, **the pith ball will be thrown off by the vibrations of the prongs.**

Experiment 139.—Place the two ends of a common friction match on convenient supports, as on two fingers of the left hand or the upper edges of a partly opened book standing on end on a table.

Strike a blow with a common tuning fork to set its prongs in vibration, bring the fork near the ear and notice the sound; quickly bring the broad face of one prong beneath the middle of the match; **the match will be thrown upward by the sudden blow.**

Experiment 140.—In similar manner, sound a fork and with the ends of the prongs, quickly touch the surface of a glassful of water. **The vibrating prongs of the sounding fork will throw two showers of spray from the water.**

319. Cause of Sound.—*All sound may be traced to the vibrations of some material body.*

The particles of a sounding body strike the adjacent particles of air, these pass the motion thus received to the air particles next beyond, and these to those still beyond.

Experiment 141.—Provide a tube four or five metres (or yards) long, and about ten centimeters (four inches) in diameter. A few lengths of common spout from the tinner's will answer. Furnish it with a funnel shaped piece, having an opening about 2½ *cm.* (one inch) in diameter. Place the tube on a table with a candle

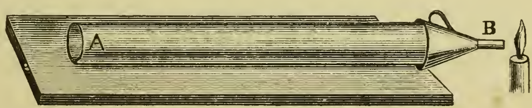

FIG. 147.

flame opposite the opening at *B*. With a book, strike a sharp blow upon the table opposite the opening at *A*. **The flame will be blown out.** Something went from *A* to *B*. Did it go through the tube?

Experiment 142.—Let us ask this question of *Nature*, speaking

with her, as we must, in the Language of Experiment. Close the opening at A and repeat the experiment: **the flame is not put out.** Remove the tube and repeat the blow; **the flame is not put out.**

The answer has come. The tube is necessary; whatever blew out the candle, *did* go through the tube.

Experiment 143.—Was this something a wind or a wave? We must ask our question in the same language as before; we must make an experiment. Dissolve as much potassium nitrate (saltpeter), as you can in half a cupful of hot water. Soak a piece of unsized paper in this liquid and dry it. This "touch-paper" burns with much smoke but no flame. Burn the paper in the tube near A, filling that end of the tube with smoke. Repeat the experiment as before. **No smoke issues at B.** Another answer has come; *it was not a wind that passed through the tube.*

Experiment 144.—Replace the tin tube by about the same length of rubber tube, that has an internal diameter of from ten to fifteen *mm.* ($\frac{1}{2}$ inch). Thrust the neck of a tin or glass funnel into the end of the tube at A. Get a few inches of glass tubing that will fit snugly into the rubber tubing. Heat the middle of the glass in a flame until it softens. Slowly draw the ends asunder until the softened part is reduced to a diameter of about two *mm.* Break the tube at this narrow neck and push the large end of one piece into the rubber tube at B. Place a *small* flame opposite the small opening of the glass tube. Strike a blow in front of the funnel at A and notice that a puff or pulse of air blows the flame. Make a loose loop in the rubber tube and repeat the experiment. Clap the hands at A and notice the series of puffs at B. While an assistant is clapping his hands at A, pinch the rubber tube so as to prevent the motion from passing through it. **Notice that the puffs at B cease while the tube is thus pinched and reappear as soon as the tube is released.**

320. Propagation of Sound.—Sound is ordinarily propagated through the air. The first layer of air is struck by the vibrating body. The particles of this

layer give their motion to the particles of the next layer, and so on until the particles of the last layer strike upon the drum of the ear.

(*a.*) See *Elements of Natural Philosophy*, § 422, *a.* If the teacher or pupil has a copy of Alfred M. Mayer's little book on "*Sound*," he may well read the explanation of the propagation of sound given on p. 89. He will also do well to make and use Crova's Disk, as described in Experiment 58 of that book. If necessary, the pupils should "club together" and buy the book *for the class.*

321. Wave Length.—In such a series of similar waves, measuring in the direction in which the waves are traveling, *the distance from any vibrating particle to the next particle that is in the same relative position or "phase" is called a wave length.* In the case of water waves, for example, the horizontal distance from one crest to the next crest would be a wave length. *The wave length may be found by dividing the velocity by the number of vibrations.*

(*a*). Every one knows how to produce a series of waves in a rope as shown in Fig. 148, each curved line of which we may

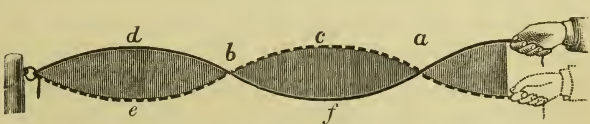

FIG. 148.

imagine to be an instantaneous photograph of a rope thus shaken. The distance *ab* or *cd* is a wave length.

322. Amplitude.—*Amplitude means the distance between the extreme positions of the vibrating particle,* or the length of its journey. Referring to Fig. 148, the distance *de* or *cf* is the amplitude of the wave.

Experiment 145.—Hold one end of a straight spring, as a hickory stick, in a vise, pull the free end to one side and let it go. Elasticity will return it to its position of rest, kinetic energy will carry it beyond and so on, a vibratory motion being thus produced. (Fig. 149.) When the spring is long, the vibrations may be seen. By lowering the spring in the vise, the vibrating part is shortened, the vibrations reduced in amplitude and increased in rapidity. As the spring is shortened, the vibrations become invisible but audible, showing that a sufficiently rapid vibratory motion may produce a sound.

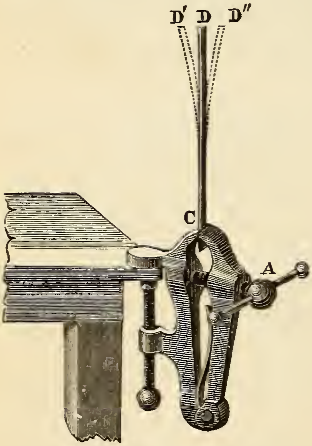

Fig. 149.

323. Sound Waves.—The layers of air are crowded more closely together by each outward vibration of the sounding body; a condensation of the air is thus produced. As the sonorous body vibrates in the opposite direction, the nearest layer of air particles follow it; a rarefaction of the air is thus produced.

A sound wave, therefore, consists of two parts, a condensation and a rarefaction.

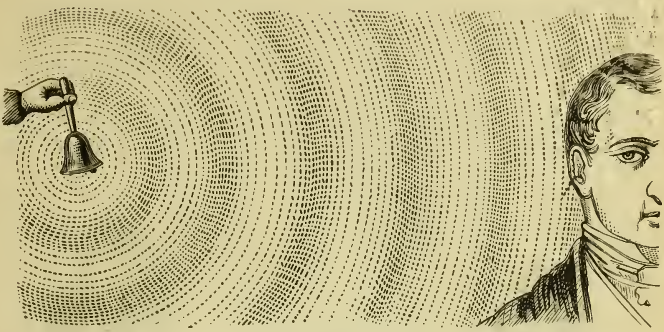

FIG. 150.

The motion of any air particle is backward and forward in the line of propagation, and not "up and down" across that line, as in the case of water waves.

Experiment 146.—Provide a wooden rod about half an inch square (or 1 inch by ¼ inch) and five or six feet long. Place one end of this rod (preferably made of light, dry pine) against the panel of a door, hold the rod horizontal and place the handle of a vibrating tuning-fork against the other end. **Notice the sound given out by the panel.**

Experiment 147.—With the help of an assistant, vary the last experiment by placing one end of the rod against the ear or between the teeth instead of against the panel. See if the sound of the fork at the same distance is perceptible without the help of the rod.

Experiment 148.—Make a "string telephone" as follows: melt the bottoms from two small, round, tin boxes about an inch or an inch and a half in diameter. Ground spices are often sold in boxes of the kind desired. The bottom may be removed by setting it for a moment on a hot stove. Over one end of each tube thus provided, firmly tie a piece of well-soaked bladder, which

may be had of a butcher or apothecary. When the bladder is dry, pass one end of a long, fine string through the middle of the head of each tin box and tie a knot in each end of the string to prevent it from drawing back. The knot should be on the inside of the box. Let one pupil hold the open end of one box to his ear, the other box being held by another pupil at such a distance that the

FIG. 151.

string shall be drawn tight. If this pupil bring the foot of a vibrating tuning-fork to the tin, the vibration will travel along the string and the sound be heard by the first pupil. If the string be a hundred feet long or more and tightly stretched, **conversation may be carried on through the apparatus.** It is desirable that no solid touch the string between the tin boxes.

324. Sound Media.—*Any elastic substance may become the medium for the transmission of sound, but such a medium is necessary. Sound cannot be transmitted through a vacuum.*

(*a.*) Soldiers and Indians sometimes detect the approach of the enemy at a great distance by putting their ears to the ground.

325. **Velocity of Sound in Air.**—The transmission of sound is not instantaneous. The blow of a hammer is often seen several seconds before the sound is heard; steam escaping from the whistle of a distant locomotive becomes visible before the shrill scream is audible; the lightning precedes the thunder.

The velocity of sound in air at the freezing temperature is about 332m., or 1090 ft. per second.

The freezing temperature is 32 degrees by Fahrenheit's thermometer or zero by the centigrade thermometer. (§ 360.)

(*a.*) The velocity above given is more than 600 miles an hour. A wind of 75 miles an hour is a terrible hurricane. Fortunately, we are here dealing with wave motion and not with wind motion.

326. **Effect of Temperature upon Velocity.**—*There is an added velocity of about 1.12 feet for every Fahrenheit degree, or of 2 feet (60 centimeters) for every centigrade degree of increase of temperature.*

Thus, the velocity of sound in air at a temperature of 59° F. or 15° C. is about 1120 ft.

327. **Continuous Sound.**—A sound may be momentary or continuous. A momentary sound consists of a single pulse produced by a single and sudden blow. A continuous sound consists of a rapid succession of pulses.

The ear is so constructed that its vibrations disappear very rapidly but the disappearance is not instantaneous.

If the motion imparted to the auditory nerve by each individual pulse continue until the arrival of its successor, the sound will be continuous.

(*a.*) Momentary sounds may be produced by pounding with a hammer, stamping with the foot, clapping the hands or drawing a stick slowly along the pickets of a fence. Continuous sounds may be produced by sawing boards or filing saws. They are more or less familiar in the rattling of wheels over a stony pavement, the roar of waves or the crackling of a large fire.

328. Noise and Music.—The sensation produced by a series of blows coming at irregular intervals, is unpleasant and the sound is called a noise. But when the air waves come with sufficient rapidity to render the sound continuous and with perfect regularity, the sensation is pleasant and the sound is said to be musical.

To secure this pleasing smoothness of music, the sounding body must vibrate with the unerring regularity of the pendulum, but impart much sharper and quicker shocks to the air. Every musical sound has a well-defined period and wave length.

329. Elements of Musical Sounds. — Musical sounds or tones have three elements—intensity or loudness, pitch and quality.

330. Intensity and Amplitude.—*Loudness of sound depends upon the amplitude of vibration. The greater the amplitude, the louder the sound.*

(*a.*) If the middle of a tightly-stretched cord or wire, as a guitar string, be drawn aside from its position of rest and then set free, it will vibrate to and fro across its place of rest, striking the air and sending sound waves to the ear. If the middle of the string be drawn aside to a greater distance and then set free, the swing to and fro will be increased, harder blows will be struck upon the air and the air particles will move forward and backward through a greater distance. In other words, the *amplitude of vibration* has been increased and we say that the sound is louder. (See Mayer's "*Sound,*" Experiment 93.)

Experiment 149.—Whisper into one end of a length (50 ft.) of garden hose. **A person listening with his ear at the other end of the hose can distinctly hear what is said** although the sound be inaudible to a person holding the middle of the hose.

331. Acoustic Tubes.—If the sound wave be not allowed to expand as a spherical shell, the energy of the wave cannot be diffused. In acoustic tubes (Fig. 152), this diffusion is prevented; *the waves are propagated in only one direction.* In this way, sound may be transmitted to great distances without considerable loss of intensity.

Experiment 150.—Draw the finger nail across the teeth of a comb, slowly the first time and rapidly the second time. Notice the difference in the sounds.

332. Pitch.—The second element of a musical sound is pitch, the quality that makes the difference between a low tone and a high tone.

FIG. 152.

The pitch of a sound depends upon the rapidity of vibration of the sounding body. The more rapid the vibrations, the higher the tone.

(*a.*) That pitch depends upon rapidity of vibration, may be shown satisfactorily by means of Savart's wheel, shown in Fig. 153. This consists of a heavy, metal ratchet-wheel, supported on a frame and pedestal The wheel may be set in rapid revolution by a cord wound around the axis. By holding a card against the teeth, when in rapid motion, a shrill tone will be produced, gradually falling in pitch as the speed is lessened. (See Mayer's "*Sound*," Experiments 77–80.)

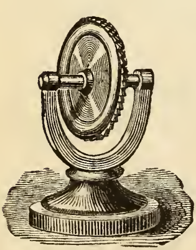

FIG. 153.

333. Reflection of Sound.—When a sound ray strikes an obstacle, it is reflected in obedience to the principle given in § 57.

(*a.*) "The great dome of St. Paul's Cathedral in London is so constructed that two persons at opposite points of the internal gallery, placed in the drum of the dome, can talk together in a mere whisper. The sound is transmitted from one to the other by successive reflections along the course of the dome."

A similar phenomenon is observable in the dome of the Capitol at Washington. The "guides" about the building will point out for you the proper position in the gallery of the dome and also certain places on the floor of Statuary Hall (formerly the Hall of Representatives), where remarkable acoustic phenomena may be noticed.

334. Recapitulation.—To be amplified by the pupil for review.

SOUND.
- DEFINITION.
- CAUSE.
- WAVES...........
  - MODE OF PROPAGATION.
  - LENGTH.
  - AMPLITUDE.
  - PARTS..........
    - *Condensation.*
    - *Rarefaction.*
- MEDIA.
- VELOCITY .. ...
  - AT FREEZING TEMPERATURE.
  - AT OTHER TEMPERATURES.
- MOMENTARY.
- CONTINUOUS...
  - NOISY.
  - MUSICAL..
    - *Loudness.*
      - Cause.
      - Acoustic Tubes.
    - *Pitch*.......Cause.
    - *Quality.*
- REFLECTION...
  - LAW.
  - WHISPERING GALLERIES.

EXERCISES.

1. Make a pencil sketch of an "up-and-down" wave having a length of two inches and an amplitude of half an inch.

2. Water is just beginning to freeze in the open air. What is the velocity of sound?

3. If a tuning fork vibrates 256 times a second and its sound travels 1280 feet in a second, what is the wave length?

4. The thermometer records a freezing temperature. In a second, 218 sound waves pass a given point. What is the length of each wave? *Ans.*—5 feet.

5. What is the rate of vibrations of a body that produces sound waves just a meter long when it is just freezing cold?

6. What is the velocity of sound in air at a temperature of 20° C.? *Ans.*—1130 feet.

7. When sound has a velocity of 1126 feet per second, what is the temperature? *Ans.*—It is 18° C.

8. Give the definition and correct pronunciation of the word *acoustics*.

SECTION II.

THE TELEPHONE—COMPOSITION AND ANALYSIS OF SOUNDS.

335. **The Telephone.**—This instrument is represented in section by Fig. 154. *A* is a permanent bar magnet, around one end of which is wound a coil, *B*, of fine copper wire carefully insulated. The ends of this coiled wire are attached to the larger wires, *CC*, which

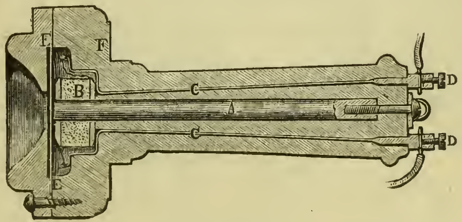

FIG. 154.

communicate with the binding posts, *DD*. In front of the magnet and coil is the soft iron diaphragm, *E*, which corresponds to the disc, *a*, of Fig 144.

In front of the diaphragm is a wooden mouth-piece with a hole, about the size of a dime, at the middle of the diaphragm and opposite the end of the magnet. The outer case is made of wood or of hard rubber. The external appearance of the complete instrument is represented by Fig. 155. The binding posts of one instru-

ment being connected by wires with the binding posts of another at a distance, conversation may be carried on between them. Carefully review §§ 314 and 315.

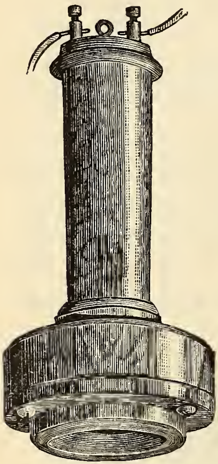

Fig. 155.

336. Action of the Telephone.—When the mouth-piece is brought before the lips of a person who is talking, air waves beat upon the diaphragm and cause it to vibrate. Each vibration of the diaphragm induces an electric current in the wire of *B*. These currents are transmitted to the coil of the connected telephone, at a distance of, perhaps, several miles, and there produce vibrations exactly like the original vibrations produced by the voice of the speaker. These vibrations of the second diaphragm send out new air waves. The two sets of air waves being alike, the resulting sensations produced in the hearers are alike. Not only different words but also different voices may be recognized. Remember that an electric current, and not sound waves, passes along the line wire. The arrangement being the same at both stations, the apparatus works in either direction. No battery is necessary with this arrangement.

337. The Transmitter.—In practice, a transmitter, shown at *C* in Fig. 156 is generally used. The vibrations of the diaphragm of *C*, when acted upon by sound waves,

produce a varying pressure upon a carbon button placed in the circuit of a galvanic battery, *D*. This varying pressure results in a varying resistance to the passage of the

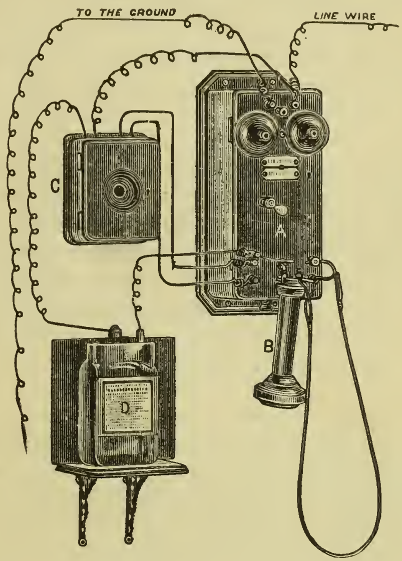

FIG. 156.

current through the button and, consequently, in variations in the current itself. This varying current, passing through the primary circuit of a small induction coil in the box, *C*, induces a current in the secondary circuit thereof. This current, thus induced, flows over the telephone wires and, at the other station, passes through a telephone like that shown at *B*, which is held close to the ear of the listener.

The message is transmitted by C at one station and received by B, of a similar instrument at the other station.

At each station are placed electric bells, A, which may be rung from the other station, for the purpose of attracting attention. When the stations are a considerable distance apart, one binding post of each instrument may be connected with the earth, as in the case of the telegraph. See Fig. 156.

(*a*.) In most of our cities, the telephones are connected by wire with a central station, called a telephone exchange. The "Exchange" may thus be connected with the houses of hundreds of patrons in all parts of the city or even in different cities. Upon request by telephone, the attendant at the central station connects the line from any instrument with that running to any other instrument. Thus, each subscriber may communicate directly with any other subscriber to the exchange.

Experiment 151.—The effect of repeated impulses, each feeble *but acting at the right instant*, may be forcibly illustrated as follows: Support a heavy weight, as a bucket of coal, by a long string or wire. To the handle of a bucket, fasten a fine cotton thread. By repeated pulls upon the thread, each pull after the first one being given just as the pendulum is beginning to swing toward you from the effect of the previous pull, the weight may be made to swing through a large arc, while a single pull *out of time* will snap the thread. A little practice will enable you to perform the experiment neatly.

Experiment 152.—Vary the last experiment by setting the pendulum in motion by well-timed puffs of air from the mouth or from a hand bellows.

The same principle is illustrated in the action of the spring board, familiar to most boys, who know that the desired effect can be secured only by "keeping time." Soldiers are often or-

dered to "break step" in crossing a bridge, lest the *accumulated energy* of many footfalls in unison break the bridge.

Experiment 153.—Suspend several pendulums from a frame as shown in Fig. 157. Make two of equal length so that they will vibrate at the same rate. *Be sure that they will thus vibrate.* The other pendulums are to be of different lengths. Set *a* in vibration. The swinging of *a* will produce slight vibrations in the frame which will, in turn, transmit them to the other pendulums. As the successive impulses thus imparted by *a* keep time with the vibrations of *b*, this energy accumulates in *b*, which is soon set in perceptible vibration.

FIG. 157.

As these impulses do not keep time with the vibrations of the other pendulums, there can be no such *accumulation of energy* in them, for many of the impulses will act in opposition to the motions produced by previous impulses and tend to destroy them.

Experiment 154.—Place two mounted tuning forks (Fig. 159) several feet apart. The forks must be exactly in unison. Sound one fork by rapidly separating its prongs with a wooden rod or by drawing a resined bass-viol bow across their ends. After a few seconds, stop the vibrations of this fork with the fingers; it will be found that the other fork has been put into sympathetic vibration and is giving forth a sound. Weight one of the prongs of the second fork with wax; an attempt to repeat the experiment will fail.

Experiment 155.—Tune, to unison, two strings upon the same sonometer (Fig. 158). Upon one string, place two or three paper riders. With a violin bow, set the other string in vibration. The sympathetic vibrations thus produced will be shown by the

dismounting of the riders, whether the vibrations be audible or not.

Change the tension of one of the strings, thus destroying the unison. Repeat the experiment and notice that the sympathetic vibrations are not produced.

338. Sympathetic Vibrations.—The string of a violin may be made to vibrate audibly by sounding near it a tuning-fork of the same tone. By prolonging a vocal tone near a piano, one of the wires seems to take up the note and give it back of its own accord. If the tone be changed, another wire will give it back. Thus the vibrations of the strings may produce sonorous waves and the waves, in turn, may produce vibrations in another string.

The string absorbs only the particular kind of vibration that it is capable of producing.

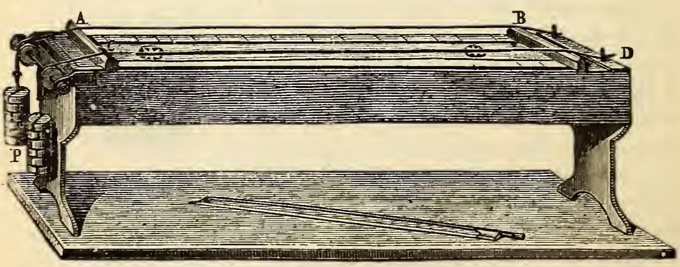

FIG. 158.

(*a.*) The sonometer box may be made by any carpenter. It is about fifty-nine inches long, $4\frac{3}{4}$ inches wide and $4\frac{3}{4}$ inches deep. The ends are made of inch oak boards, the sides of $\frac{1}{2}$ inch oak boards and the top of $\frac{1}{8}$ inch pine board. The top should be glued

on; no bottom is needed; the box may sit directly on the table. Three or four one-inch holes may well be bored in each side-piece. The two bridges, shown at *A* and *B* (Fig. 158) should be of very hard wood and glued to the cover just $47\frac{3}{4}$ inches (120 centimeters) apart, measured from centre to centre. The strings may be such as are used on bass-viols; they should be alike. Two similar pieces of piano-forte wire (large size) may be used. The strings may be stretched by weights as shown in the figure or by two piano string pegs turned with a wrench or a piano tuner's key. The familiar screw arrangement of the bass-viol may be used for the purpose. If piano wires are used for strings, the ends must be annealed by heating them red hot and cooling them slowly, so that they may remain fixed when wound around their fastenings. Lines should be drawn across the top of the box, exactly dividing the distance between the middle of the bridges (at which points the strings are supported) into halves, thirds and quarters. Provide a block of wood, about two inches wide, $4\frac{1}{2}$ inches long and just thick enough to slip between the strings and the top of the box.

(*b*.) When the two strings are in unison, they will vibrate at exactly the same rate. The second and subsequent pulses sent out by the first string strike the second string, already vibrating from the effect of the first pulse, in the same phase of vibration, and thus each adds its effect to that of all its predecessors. If the strings be not in unison, they will vibrate at different rates and but few of the successive pulses can strike the second string in the same phase of vibration; the greater number will strike it at the wrong instant.

Experiment 156.—Strike a tuning-fork held in the hand. Notice that the sound heard is feeble. Strike the fork again and place the end of the handle upon a table. The loudness of the sound heard is remarkably increased. Repeat Experiment 146.

Experiment 157.—Strike the fork and hold it near the ear,

counting the number of seconds that you can hear it. Strike the fork again with equal force, place the end of the handle on the table and count the number of seconds that you can hear it.

339. **Sounding-boards.**—In the case of the sonometer, piano, violin, guitar, *etc.*, the sound is due more to the vibrations of the resonant bodies that carry the strings than to the vibrations of the strings themselves. The strings are too thin to impart enough motion to the air to be sensible at any considerable distance; but as they vibrate, their tremors are carried by the bridges to the material of the sounding apparatus with which they are connected.

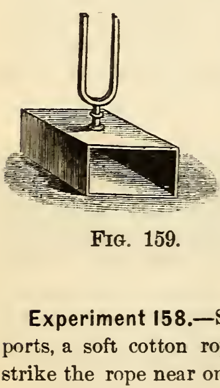

Fig. 159.

These larger surfaces throw larger masses of air into vibration and thus greatly intensify their sound. It necessarily follows that the energy of the vibrating body is sooner exhausted; the sounds are of shorter duration.

(*a.*) For class or lecture experiments, tuning-forks should be mounted as shown in Fig. 159.

Experiment 158.—Support horizontally, between two fixed supports, a soft cotton rope a few yards in length. With a stick, strike the rope near one end a blow from below and a crest will be

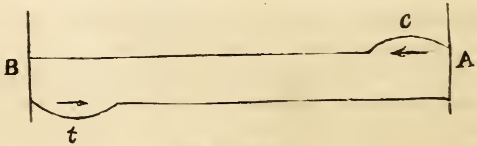

Fig. 160.

formed as shown in Fig. 160. Vary the tension of the rope, if necessary, until the crest is easily seen. Notice that the crest, *c*, travels from *A* to *B* where it is reflected back to *A* as a trough, *t*.

By striking the rope from above, a trough may be started which will be reflected as a crest. See Mayer's "Sound," Experiment 57, in which the wire spring shows *waves of condensation and rarefaction.* Tie a piece of string to one turn of the wire and notice the motion of the string as the wave passes.

Experiment 159.—Start from *A* a trough. At the moment of its reflection as a crest at *B*, start a crest at *A* as shown in Fig. 161. The two crests will meet near the middle of the rope. The crest at the point and moment of meeting results from two forces acting

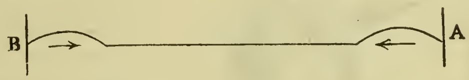

Fig. 161.

in the same direction consequently, it will be greater than either of the component crests.

340. Coincident Waves.

—In the case of water waves, when crest coincides with crest, the water reaches a greater height. So with sound waves, *when condensation coincides with condensation, this part of the wave will be more condensed; when rarefaction coincides with rarefaction, this part of the wave will be more rarified.*

This increased difference of density in the two parts of the wave means increased loudness of sound, because there is an increased amplitude of vibration for the particles constituting the wave.

341. Reinforcement of Sound.—This increased intensity may result from the blending of two or more series of similar waves in like phases, or from the union of direct or reflected waves in like phases.

Under such circumstances, one set of waves is said to reinforce the other. The phenomenon is spoken of as the reinforcement of sound.

Experiment 160.—Hold a sounding tuning-fork over the mouth of a glass jar, 18 or 20 inches deep; a feeble sound is heard. Carefully pour in water until the liquid reaches such a level that the sound suddenly becomes much louder. **The water has shortened the air column until it is able to vibrate in unison with the fork.** The length of the air column is one-fourth the length of the wave produced by the fork.

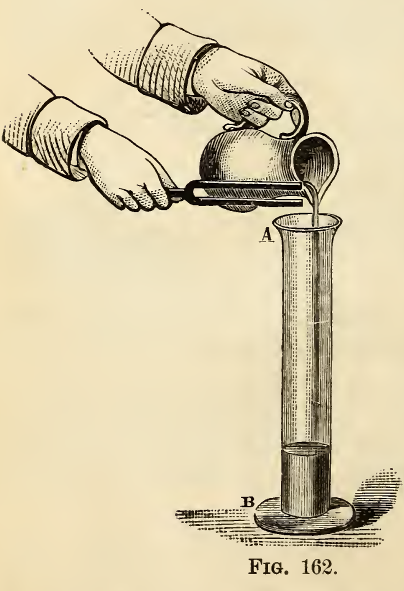

FIG. 162.

342. Resonance.—*Resonance is a variety of the reinforcement of sound due to sympathetic vibrations.* The resonant effects of solids were shown in § 339. The resonance of an air

column was shown in the last experiment. The loudness of sound of wind instruments, like the pipes of a church organ, is largely due to the resonance of the air enclosed in them.

343. Helmholtz's Resonators. — Helmholtz, the German physicist, constructed a series of resonators, each one of which resounds powerfully to a single tone of certain pitch or wave length. They are metallic vessels, nearly spherical, having a large opening, as at A in Fig. 163, for the admission of the sound waves. The funnel-shaped projection at B has a small opening and is inserted in the outer ear of the observer.

FIG. 163.

Experiment 161.—Using the rope as described in Experiment 158, start a crest at A. At the moment of its reflection at B as a trough, start a second crest at A. The trough and crest will meet near the middle of the rope. The rope at this time and place will be urged upward by the crest and downward by the trough. The

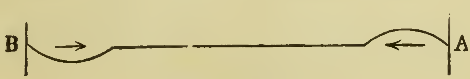

FIG. 164.

resultant effect of these opposing forces will, of course, be equal to their difference. If crest and trough exert equal forces, the difference will be zero. Consequently the motion of the rope at

the meeting of crest and trough will be little or nothing. **Thus one wave motion may be made to destroy the effect of another wave motion.**

Experiment 162.—Hold a vibrating tuning-fork near the ear and slowly turn it between the fingers. During a single complete rotation, **four positions of full sound and four positions of perfect silence will be found.** When a side of the fork is parallel

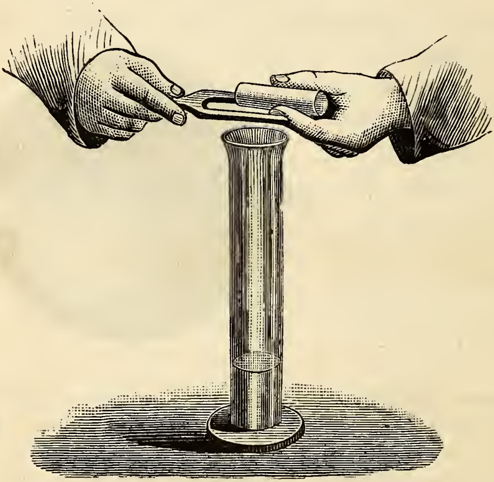

FIG. 165.

to the ear, the sound is plainly audible; when a corner of the prong is turned toward the ear, the waves from one prong completely destroy the waves started by the other.

Experiment 163.—Over a resonant jar, as shown in Fig. 164, slowly turn a vibrating tuning-fork. In four positions of the fork we have loud, resonant tones; in four other positions we have complete interference. While the fork is in one of these positions

of interference, place a pasteboard tube around one of the vibrating prongs, Fig. 167; **a resonant tone is instantly heard**; the cause of the interference has been removed. (See Mayer's "*Sound*," Experiments 60 to 67.)

344. Interference of Sound.—If, while a tuning-fork is vibrating, a second fork be set in vibration, the waves from the second must traverse the air set in motion by the former. If the waves from the two forks be of equal length, as will be the case when the two forks have the same pitch, and the forks be any number of whole wave lengths apart, the two sets of waves will unite in like phases (Fig. 166), condensation with condensation, *etc.*, and a reinforcement of sound will ensue.

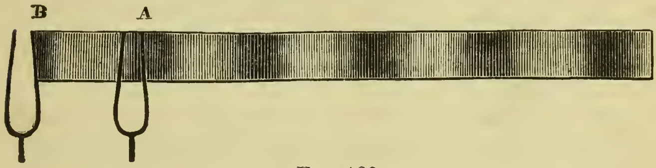

Fig. 166.

But if the second fork be placed an odd number of half wave lengths behind the other, the two series of waves will meet in opposite phases; where the first fork requires a condensation, the second will require a rarefaction. The two sets of waves will interfere, the one with the other. If the waves be of equal intensity, the air particles, thus acted upon, will remain at rest; this means silence. In Fig. 167, an attempt is made to represent this effect to the eye, the uniformity of tint indicating the absence of condensations and rarefactions.

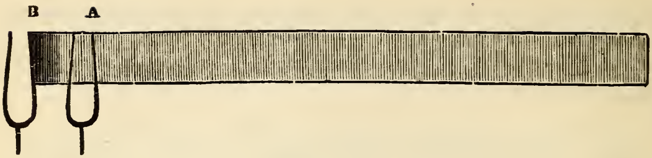

Fig. 167.

By adding sound to sound, both may be destroyed. This is the leading, characteristic property of wave motion. The phenomenon here described is called interference of sound.

(*a.*) The sound of a vibrating tuning-fork held in the hand is almost inaudible. The feebleness results largely from interference. As the prongs always vibrate in opposite directions at the same time, one demands a rarefaction where the other demands a condensation. By covering one vibrating prong with a pasteboard tube, the sound is more easily heard.

Experiment 164.—Use the two forks mentioned in Experiment 154, one of them being loaded with wax. Set both forks in vibration and **notice the palpitating effect.**

Experiment 165.—In a quiet room, strike simultaneously one of the lower white keys of a piano and the adjoining black key. **The palpitating effect will be heard.**

345. **Beats.**—If two tuning-forks, *A* and *B*, vibrating respectively 255 and 256 times a second, be set in vibration at the same time, their first waves will meet in like phases and the result will be an intensity of sound greater than that of either. After half a second, *B* having gained half a vibration upon *A*, the waves will meet in opposite phases and the sound will be weakened

or destroyed. At the end of the second, we shall have another reinforcement; at the middle of the next second, another interference.

This peculiar palpitating effect is due to a succession of reinforcements and interferences, and is called a beat.

The number of beats *per* second equals the difference of the two numbers of vibrations. (See Mayer's "Sound," Experiments 71 and 72.

346. Vibrations of Strings.—The laws of musical tones are best studied with the help of stringed instruments. The Laws of the Vibrations of Strings is treated in § 455 of the *Elements of Natural Philosophy.*

Experiment 166.—Give a fixed support to one end of a rubber tube about two yards long and hold the other end in the hand. Move the hand up and down so as to send a series of waves along the tube. By varying the tension of the tube and the rate of vibration of the hand, you will soon be able to produce an appearance of gauzy spindles much like those shown in Figs. 148 and 170. This gauzy appearance is due to an optical effect known as "the persistence of vision." The motion of the hand produces a regular succession of equal crests and troughs, which are reflected and neutralize each other as explained in Experiment 161.

347. Fundamental Tones and Overtones.—A string may vibrate transversely as a whole, or as independent segments. Such segments will be aliquot parts of the whole string and separated from each other by points of no motion called *nodes* or nodal points. (See *a* and *b*, Fig. 148.) The part of the string between two adjacent nodes is called a *ventral segment.*

The tone produced by the vibrations of the whole length of a string is called its fundamental tone. The tones produced by the vibrations of the segments of a string are called its overtones or harmonics.

348. Fundamental Tones.—When a string vibrates so as to produce its fundamental tone, its extreme positions may be represented by the continuous and the dotted lines of Fig. 168.

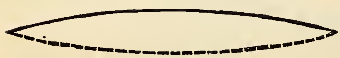

FIG. 168.

This effect is obtained by leaving the string free and bowing it near one of its ends.

If a number of little strips of paper, doubled in the middle, be placed like riders upon the string and the string bowed as just described, all of the riders will be thrown up and most of them off. This shows that the whole string vibrates as one string; that there is no part of it between the fixed ends that is not in vibration.

349. The First Overtone.—If the string of the sonometer be touched exactly at its middle with a feather, a higher tone is produced when the string is bowed. This tone is an octave higher than the fundamental. The string now vibrates in such a way that the point touched remains at rest; it is a node.

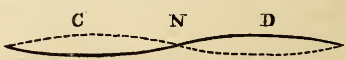

FIG. 169.

The tone is due to the vibrations of the two halves of the string, which thus give the octave instead of the fundamental. The existence of the

node and segments will continue for some time after the feather is removed. If riders be placed at C, N and D, the one at N will remain at rest while those at C and D will probably be dismounted.

(*a*.) Instead of the sonometer string, a piece of rubber tubing filled with sand and hung in a vertical position with both ends fastened may be used. Hold the middle of the tube to form a node and pluck at the middle of the lower half.

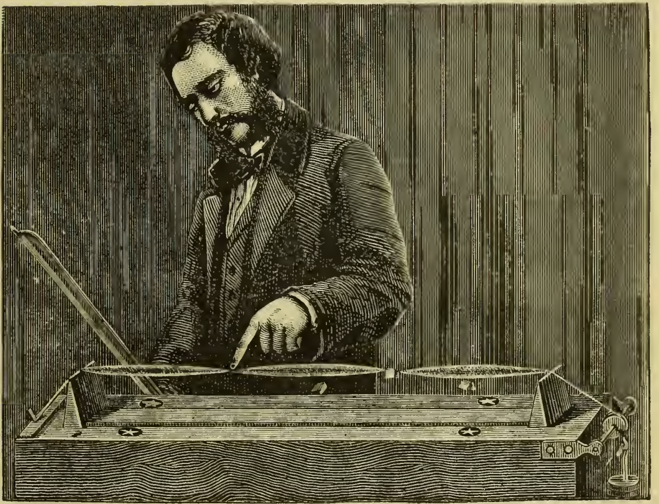

FIG. 170.

350. Higher Overtones.—In like manner, if the vibrating string be touched at exactly one-third (see Fig. 170), one-fourth or one-fifth of its length from one end, it will divide into three, four or five segments, with

vibrations three, four or five times as rapid as the fundamental vibrations.

351. Quality or Timbre.—As a sounding body vibrates as a whole and in segments at the same time, the fundamental and the harmonics blend. *The resultant effect of this blending of fundamentals and harmonics constitutes what we call the quality or timbre of the sound.*

We recognize the voice of a friend not by its loudness nor by its pitch, but by its quality. When a piano and violin sound the same tone, we easily distinguish the sound of one from that of the other because, while the fundamentals are alike, the harmonics are different.

Experiment 167.—Take your seat before the key-board of a piano. Press and hold down the key of "middle C," marked 1 in Fig. 171 which represents part of the key-board. This will lift the

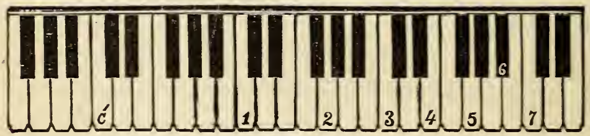

FIG. 171.

damper from the corresponding piano wire and leave it free to vibrate. Strongly strike the key of C', an octave below. Hold this key down for a few seconds and then remove the finger. The damper will fall upon the vibrating wire and bring it to rest. When the sound of C' has died away, *a sound of higher pitch is heard.* The tone corresponds to the wire of 1, which wire is now vibrating These vibrations are sympathetic with those that produced the first overtones of the wire that was struck. **These vibrations in**

the wire of 1 prove the presence of the first overtone in the vibrating wire of C′. (See § 338.)

In similar manner, successively raise the dampers from the wires of 2, 3, 4, 5, 6 and 7, striking C' each time. These wires will accumulate the energy of the waves that correspond to the respective overtones of the wire of C' and give forth each its proper tone. **Thus we analyze the sound of the wire of C′ and prove that at least seven overtones are blended with its fundamental.**

Some of these tones of higher pitch, thus produced by *vibrations sympathetic with the vibrations of the segments* of the wire of C', are feebler than others. This shows that the quality of a tone depends upon the relative intensities as well as the number of the overtones that blend with the fundamental.

352. Simple and Compound Tones.—The well trained ear can detect several sounds of different pitch when a single key of a piano is struck. In other words, the sound of a vibrating piano wire is a compound sound. The sound of a tuning fork is a fairly good example of a simple sound. Simple sounds all have the same quality, differing only in loudness and pitch.

(*a.*) A series of Helmholtz's resonators enables the student of acoustics to analyze any compound sound. Each component tone may be reproduced by a tuning fork of appropriate pitch. By sounding simultaneously the necessary number of forks, each of proper pitch and with appropriate relative intensity, Helmholtz showed that the sounds of musical instruments, including even the most wonderful one of all (the human voice), may be produced synthetically.

NOTE.—The author takes this last opportunity to advise the pupil to procure and study Mayer's "Sound." See Chapter XVII.

353. Recapitulation.—To be amplified by the pupil for review.

SOUND (continued).

- THE TELEPHONE.
  - Construction.
  - Action.........
    - *Electric.*
    - *Acoustic.*
- SYMPATHETIC VIBRATIONS.
  - Pendulum..................
  - Sonometer .... } *Resonance.*
  - Mounted Tuning-Forks... } *Resonance.*
  - Sounding Boards.......... } *Resonance.*
  - Air Columns............... } *Resonance.*
  - Helmholtz's Resonators.. } *Resonance.*
- SUPERPOSED WAVES.
  - Reinforcement............ } *Resonance.*
  - Interference...
    - *Characteristic of wave motion.*
    - *Beats.*
- TIMBRE.........
  - Fundamental tones.
  - Overtones.
- ANALYSIS OF SOUNDS.
  - Simple.
  - Compound.

EXERCISES.

1. Two forks vibrate 256 and 264 times a second respectively. (*a.*) Which yields the longer sound waves? Which produces tones of the higher pitch?

2. What is the length of waves produced by a fork vibrating 280 times a second, when a centigrade thermometer shows a temperature of 15 degrees? *Ans.*—4 feet.

3. A resonant air column (Fig. 162) is one foot long. What is the wave length of the tone to which it will respond most satisfactorily? *Ans.*—4 feet.

4. One tuning-fork vibrates 256 times a second and makes two beats *per* second with a second fork. What is the rate of vibration of the second fork?

5. Is the motion of a sound wave vibratory or progressive?

6. What is the difference between a longitudinal and a transverse vibration? Illustrate each.

7. What is the velocity of sound in a vacuum?

8. What determines the pitch of a musical tone?

REVIEW QUESTIONS.

1. (*a*.) How may one vary the pitch of a violin string? (*b*.) Describe the electrical condition of a polarized body.

2. When a door is swung open or shut by pressing with the hand near the hinges, what class of levers is illustrated?

3. Fig. 172 represents apparatus made of glass tubing and a bottle. There are openings at *a*, *b* and *c*. Tell how the apparatus may be used to transfer a liquid that is dangerous to handle, *e. g.* sulphuric acid.

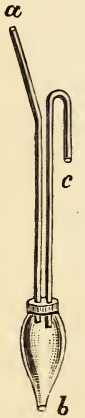

Fig. 172.

4. Describe the waves produced by throwing a stone into quiet water.

5. Describe the waves produced by striking a bell in the air.

6. What is the difference between kinetic and potential energy.

7. Define physical change and give an illustration thereof.

8. Describe the barometer.

9. What is always the divisor in problems in specific gravity?

10. What is a Kation?

11. What is meant by the length of a sound wave?

12. On a certain day at the freezing temperature, I saw the flash of a gun. Ten seconds later, I heard the report. (*a*.) What was the distance of the gun? (*b*.) Why do I state the temperature?

Fig. 173.

13. Fig. 173 represents an electric current flowing through an insulated wire wound around a piece of soft iron. What is the name of this combination?

CHAPTER VIII.

HEAT.

SECTION I.

TEMPERATURE, THERMOMETERS, EXPANSION.

Experiment 168.—Rub a brass button on the floor or carpet; it soon becomes uncomfortably warm.

Experiment 169.—Place a nail or coin on an anvil or stone and hammer it vigorously; **it soon becomes too hot to handle.** In this way, blacksmiths sometimes heat iron rods to redness.

Experiment 170.—Hold a piece of iron or steel against a dry grindstone in rapid revolution; the shower of sparks noticeable is due to the fact that **the small particles of metal torn off by the grindstone are heated to incandescence.**

354. **Heat Produced by Mechanical Energy.**—*The arresting of mechanical motion transforms visible energy into heat.* (See § 99.)

355. **A Day Dream.**—As our young philosopher notices the quickly falling blows of the blacksmith's hammer on the nail and anvil, he begins to think very intently. He knows that the descend-

ing hammer has energy for it is able to do work. He understands that this is so because the hammer has weight and motion. After the last blow has been struck and the hammer lies at rest on the anvil, he begins to wonder what has become of all the energy that he knows was in the hammer when it was in motion a moment ago. He knows that the visible, kinetic energy has disappeared, for the hammer has no motion. He cannot see that it has been transformed into potential energy. Yet he remembers that he has been told that energy, like matter, is indestructible. Here is a problem; shall he give it up? No, for he is our "young philosopher."

The puzzling problem perplexes him so that he falls into a day-dream. His "scientific imagination" begins to work. He again sees the falling hammer; he hears and, with quickened perception, almost feels the shock. The motion of the hammer, *as a hammer,* ceases; the energy of the hammer, *as a hammer,* is destroyed. But his mind's eye sees the myriad molecules of the hammer, nail and anvil, each for itself, pick up a portion of the motion lost by the hammer as though the shock had given to each a shiver. He sees that, as these molecules now have weight and motion, they necessarily have kinetic energy. He sees that, at least, part of these molecular motions were produced by the mass motion of the hammer and that the total quantity of energy thus gained by the molecules must be just equal to the quantity of energy lost by the hammer.

He then awakens; he sees the hammer, nail and anvil but he cannot see the molecular motions that were so vivid in his day-dream. He places his hand upon the iron masses and finds that they were heated by the blows. Like Archimedes, he shouts "Eureka! I cannot *see* these molecular motions but I can *feel* them. The visible energy of the moving mass would have been revealed to my hand as a crushing blow; *the invisible energy of the moving molecules is revealed to my hand as heat.*"

Experiment 171.—Pass a bent glass tube through the air-tight cork of a flask half full of water, and let it dip beneath the surface of the water. Heat the flask. **The heat will raise some**

of the water to the end of the tube where it may be caught as shown in Fig. 174.

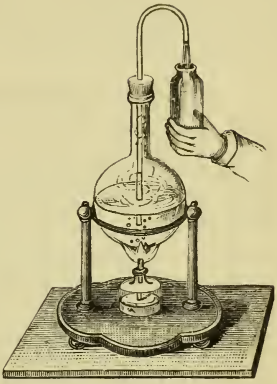

FIG. 174.

356. Mechanical Energy Produced by Heat.—Previous experiments showed us that mechanical energy can produce heat. The last experiment shows that heat can perform mechanical work; it lifted water against the force of gravity There certainly seems to be a close connection between heat and the ordinary forms of energy.

357. What is Heat?—*Heat is a form of energy. It consists of the ceaseless, vibratory motions of the molecules of matter or results from such motions and gives rise to the sensations of warmth and cold.*

358. What is Temperature?—*The temperature of a body is its condition considered with reference to its ability to communicate heat to other bodies.*

Temperature is a very different thing from *quantity of heat.* A cup of water dipped from a lake will have the same temperature as the lake, but the water in the lake will have incomparably more heat than the water in the cup.

359. Thermometers.—*An instrument for measuring temperature is called a thermometer.* The mercury thermometer is the most common.

Fig. 175.

360. Thermometric Scales.—There are two scales used in this country, the centigrade and Fahrenheit's. For these scales, the fixed points are marked as follows:

	Centigrade.	*Fahrenheit.*
Freezing point,	0°	32°
Boiling point,	100°	212°

The tube between these two points is divided into 100 equal parts for the centigrade scale and into 180 for Fahrenheit's. Hence a change of temperature of 5° C. is equal to a change of 9° F., or an interval of one centigrade degree is equal to an interval of $\frac{9}{5}$ of a Fahrenheit degree.

Experiment 172.—Provide a metal ball which, at ordinary temperatures, will easily pass through a certain ring; heat the ball and it will no longer pass through the ring. If the ball be cooled by plunging it into cold water, it will again pass through the ring. (Fig. 176.)

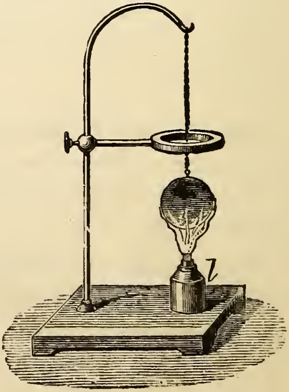

Fig. 176.

361. Expansion. — *Increase of volume is the first visible effect of heat upon bodies.*

Whatever raises the temperature of a body increases the energy with which the molecules of that body swing to and fro. Molecules thus vibrating must push each other further apart, and thus cause the body which they constitute *to expand.*

Experiment 173.—Saw a piece from one side of a large iron link and force the ends of the opened link slightly together so that the small piece may be pressed hard enough to hold it in place. When the opposite side of the link is heated, it will expand and the piece will fall out of its place.

362. Expansion of Solids.—The energy of expansion and contraction of solids, when heating and cooling, is remarkable. This expansion of metals by heat is utilized by coopers in setting hoops, by wheelwrights in setting tires, by builders in straightening bulging walls, *etc.*

363. Anomalous Expansion of Water.—Water presents a remarkable exception to the general rule. *If water at* 0° C. *be heated, it will contract until it reaches* 4° C., *its temperature of greatest density. Heated above this point, it expands.*

364. Results of this Exception.—This property of water is of great importance. Were it otherwise, the ice would sink and destroy everything living in the water. The entire body of water would soon become a solid mass which the heat of summer could not wholly melt, for, as we shall soon see, water has little power to carry heat downward.

Experiment 174.—Partly fill a bladder with cold air, tie up the opening and place the bladder near the fire. The air will expand and fill the bladder.

Experiment 175.—Heat a closed flask having a delivery tube terminating under water. Some of the expanded air will be forced to escape, and may be seen bubbling through the water. By "collecting over water" the air thus driven out, it may be accurately measured. (Fig. 177.)

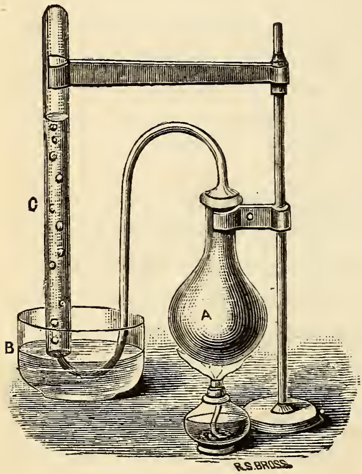

FIG. 177.

Experiment 176. — Cut a flat spiral with two or three turns from a piece of stiff writing paper about three inches in diameter, thrust a pin through the centre of the paper, take the pin by the point and hold the spiral over a hot stove or lighted lamp. Ascending currents of heated air will cause the spiral to turn about the pin as an axis.

365. Expansion of Gases.—The ascension of "fire balloons" and the draft of chimneys are due to the expansion of gases by heat. When the air in the chimney of a stove or lamp is heated, it is rendered lighter than the same bulk of surrounding air and, therefore, rises. The cooler air comes in to take its place.

366. Absolute Zero of Temperature.—*The temperature at which the molecular motions constituting heat wholly cease is called the absolute zero.* It has never been reached, and has been only approximately determined.

(*a.*) Temperature, when reckoned from the absolute zero, is called absolute temperature. Absolute temperatures are obtained by adding 460 to the reading of a Fahrenheit thermometer, or 273 to the reading of a centigrade thermometer.

367. Recapitulation.—To be amplified by the pupil for review.

- **HEAT.**
  - DEFINITION.
  - PRODUCED BY FRICTION.
  - INVISIBLE MOLECULAR ENERGY.
  - TEMPERATURE.
    - DEFINITION.
    - THERMOMETERS ....
      - Centigrade.
      - Fahrenheit.
      - (Centigrade and Fahrenheit:) *Readings.*
    - ABSOLUTE.
  - EXPANSION......
    - CAUSE.
    - SOLIDS.
    - LIQUIDS.
    - GASES.

EXERCISES.

1. If a centigrade thermometer records 15°, what will be the reading of a Fahrenheit thermometer by its side?

2. Express a temperature of 59° F. in degrees centigrade.

3. What is the absolute temperature of 15° C.? What does your answer mean?

4. How can you easily show that mechanical energy may be converted into heat energy?

5. Why does not Lake Erie freeze solid to the bottom?

6. Show how the draft of a chimney depends upon gaseous expansion.

SECTION II.

LIQUEFACTION AND VAPORIZATION.

Experiment 177.—Melt some ice in any convenient dish. When it is partly melted, stir the liquid part with a chemical thermometer and notice carefully the temperature at which ice melts. Frequently determine the temperature until the ice is all melted and notice that **the temperature is constant until the last solid particle disappears.**

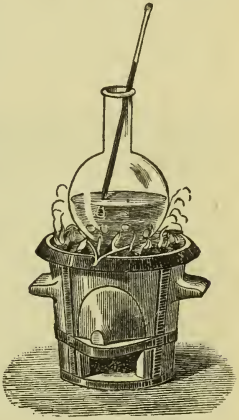

FIG. 178.

Experiment 178.—Repeat the experiment with tallow, beeswax and sulphur in succession. It may be observed, in each case, that the hotter the fire, the more rapidly the solid will melt but that there will be **no rise of temperature from the time the solid begins to melt until it is all melted.** Heat the sulphur somewhat above the melting point and allow it to cool. Notice the temperature when it begins to solidify and while it is solidifying

368. Laws of Fusion.—It has been found by experiment that the following statements are true :

(1.) *Every solid begins to melt at a certain temperature which, for a given substance, is invariable if the pressure be constant. When cooling, the substance will solidify at the temperature of fusion.*

(2.) *The temperature of the solid or liquid remains at the melting point from the moment that fusion or solidification begins until it is complete.*

369. Vaporization.—If, after liquefaction, further additions of heat be made, a point will be reached at which the liquid will pass into the aëriform condition. This change of form is called vaporization. Vaporization is of two kinds—*evaporation* and *ebullition.*

370. Evaporation.—*Evaporation signifies the quiet formation of vapor at the surface of a liquid.*

371. Ebullition.—*Ebullition or boiling, signifies the rapid formation of vapor bubbles in the mass of a liquid.* (See *Elements of Natural Philosophy,* § 501.)

Experiment 179.—In a beaker half full of water, place a thermometer and a test tube half filled with ether. (Fig. 179.) Heat the water. When the thermometer shows a temperature of about 60° C., the ether will begin to boil. The water will not boil until the temperature rises to 100° C. The temperature will not rise beyond this point.

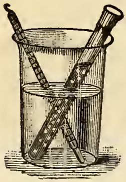

Fig. 179.

Experiment 180.—Half fill a Florence flask with water. Boil the water until the steam drives the air from the upper part of the flask. Cork tightly, remove the lamp and invert the flask. (Fig. 180.) The exclusion of the air may be made more certain by immersing the corked neck of the flask in water that has been recently boiled.

When the lamp was removed, the temperature was not above 100° C. By the time that the flask is inverted and the boiling has ceased, the temperature will have fallen below 100° C. When the boiling stops, pour cold water upon the flask ; **directly the boiling begins again.**

The cold water poured upon the flask lowers the temperature of the water in the flask still further, but it also condenses some of the steam in the flask or reduces its tension (§ 179). This reduction of the tension lessens the work necessary to boiling. There being enough heat in the water to do this lessened amount of work, the water again boils and increases the pressure until the boiling point is raised above the temperature of the water.

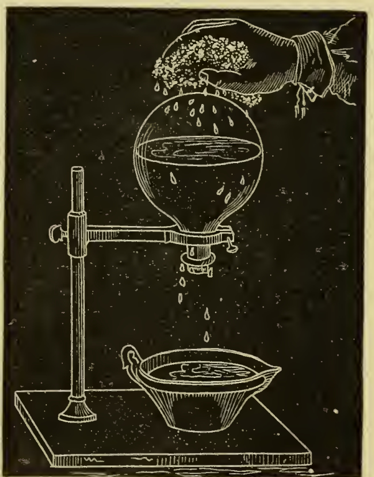
Fig. 180.

The flask may be drenched and the water made to boil a dozen times in succession with a single heating. The experiment may be made more striking by plunging the whole flask under cool water.

While water boils at 212° F. under a pressure of one atmosphere, it must be heated to about 250° F. to boil under a pressure of two atmospheres or to more than 350° F., under a pressure of ten atmospheres.

372. Laws of Ebullition.

(1.) *Every liquid begins to boil at a certain temperature, which, for a given substance, is in-*

variable if the pressure be constant. When cooling, the substance will liquefy at the boiling point.

(2.) *The temperature of the liquid, or vapor, remains at the boiling point from the moment that it begins to boil or liquefy.*

(3.) *An increase of pressure raises the boiling point; a decrease of pressure lowers the boiling point.*

373. Concerning Steam.—*A given mass of water in the aeriform condition occupies nearly 1700 times as much space under a pressure of one atmosphere as it does in the liquid condition.* In other words, a cubic inch of water will yield nearly a cubic foot of steam.

Steam is invisible. What is commonly called steam is not true steam, but little globules of water condensed by the cold air and suspended in it. By carefully noticing the steam issuing from the spout of a tea-kettle, it will be observed that for about an inch from the spout there is nothing visible. The steam there has not had opportunity for condensation. The water particles visible beyond this space passed through it as invisible steam. The steam in the flask of Fig. 180 is invisible.

Experiment 181.—Boil water colored with ink in the flask, *a*. (Fig. 181.) The steam passes through the delivery tube into *c* which is placed in a vessel of iced water. The steam that condenses in the delivery tube and the smaller flask will be found to be colorless water. The ink has been left in *a*.

374. Distillation.—*Distillation is a process of separating a liquid from a solid which it holds in solution, or of separating a mixture of two liquids having different boiling points.* The process depends upon the fact that different substances are vaporized at different temperatures.

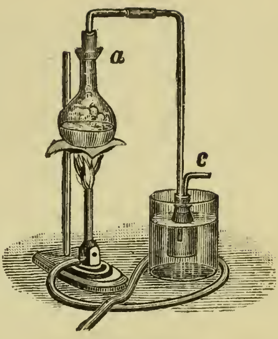

FIG. 181.

The apparatus, called a still, is made in many forms, but consists essentially of two parts—the retort for producing vaporization, and a condenser for changing the va-

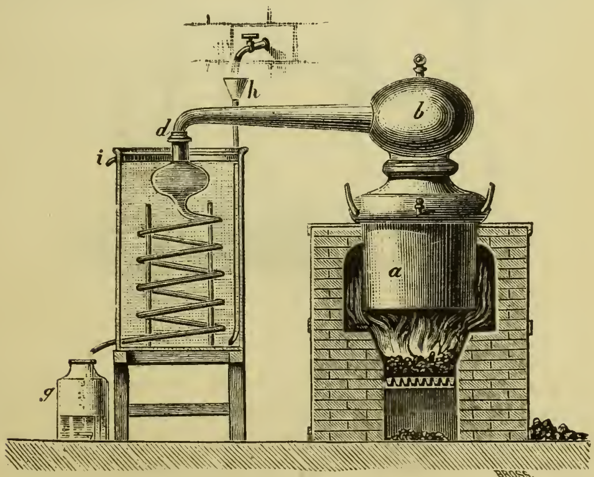

FIG. 182.

por back to the liquid form. Fig. 182 represents one form of the apparatus. It consists of a retort, *ab*, the neck of which is connected with a spiral tube, *dd*, called the *worm*. The worm is placed in a vessel containing water. This vessel is continually fed with cold water carried to the bottom by the tube *h*. As the water is warmed by the worm it rises and overflows at *i*.

(*a*.) Suppose that water is to be separated from the salt it holds in solution. The brine is placed in a retort and heated a little above 212° F. At this temperature, the water is vaporized while the salt is not. The steam is driven from the retort through the worm, where it is rapidly condensed and passes into a vessel, *g*, prepared to receive it. The salt remains in the retort, *a*.

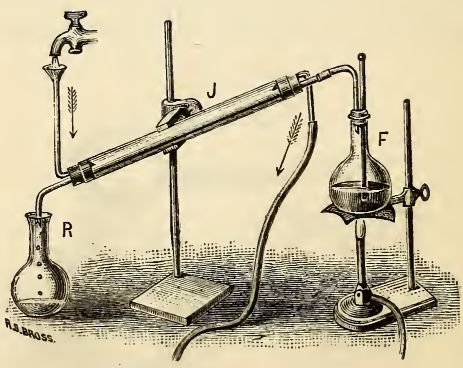

FIG. 183.

(*b*.) Fig. 183 represents a simpler form of apparatus for this purpose. The retort is a Florence flask, *F*, the delivery tube of which passes through a "water-jacket," *J*. The method of supplying this condenser with cold water is evident from the figure.

(*c*.) Suppose that alcohol is to be separated from water. The

solution is placed in the retort and heated about 90° C., which is above the boiling point of alcohol but below that of water. The alcohol will pass over in a state of vapor and be condensed, while the water, *etc.*, remain behind.

375. Recapitulation.—To be amplified by the pupil for review.

- **CHANGE OF PHYSICAL CONDITION.**
  - LIQUEFACTION.—Laws.
  - VAPORIZATION.
    - Evaporation.
    - Boiling....
      - *Definition.*
      - *Laws.*
      - *Effect of Pressure.*
      - *Steam.*
      - *Distillation.*

EXERCISES.

1. Sulphur begins to melt at 115° C. At which temperature will melted sulphur begin to solidify?

2. What is the difference between evaporation and ebullition?

3. How can water be heated above the ordinary boiling point?

4. On the top of high mountains, water boils at so low a temperature, owing to diminished atmospheric pressure, that it does not become hot enough to cook many kinds of food. Can you suggest a remedy for this difficulty?

5. What does steam look like?

6. What fact underlies all processes of distillation?

7. How may sea water be rendered fit for drinking?

8. Ice and snow are being melted in a kettle over a hot fire. How warm can they be made before they are wholly melted?

9. A cubic foot of water is vaporized. (*a.*) What is the volume of the steam under a pressure of one atmosphere? (*b.*) Under a pressure of two atmospheres? (See Exercise 7, page 137.)

SECTION III.

LATENT AND SPECIFIC HEAT.

376. **Thermal Units.**—*A thermal or heat unit is the amount of heat necessary to warm a weight unit of water one degree above the freezing point.* The weight unit generally used is the gram or pound; any other weight unit may be used with equal propriety. The degree may be centigrade or Fahrenheit.

(*a.*) We have two units in common use. They are the amounts of heat necessary to warm

(1.) A gram of water from 0° C. to 1° C.
(2.) A pound of water from 32° F. to 33° F.

Experiment 182.—Take a block of ice at a temperature of —10° C. (14° F.) and warm it. A thermometer placed in it rises to 0° C. The ice begins to melt, but the mercury no longer rises. **Heat is still applied but the thermometer remains stationary until the last particle of ice has been liquefied.** Then the temperature begins to rise and continues to do so until the thermometer marks 100° C. **The water then begins to boil, and the temperature a second time becomes fixed.** *See Elements of Natural Philosophy*, §§ 515–517.

377. **Definition of Latent Heat.**—*The latent heat of a substance is the quantity of heat that must be communicated to a body to change its condition without changing its temperature.*

It may be made to reappear as sensible heat during the opposite changes, after any interval of time.

378. Latent Heat of Fusion.—When ice or any other solid is melted by the direct application of heat, much of the heat is rendered latent. We may represent the process of liquefaction of ice as follows :

Water at 0° C. = ice at 0° C + latent heat of water.

Experiment 183.—Mix two weights of pulverized ammonium nitrate and one weight of pulverized ammonium chloride (sal ammoniac) and dissolve the mixture in three weights of *cold* water, stirring the substances together with a small test tube containing a little cold water. Determine the temperature of the dissolved mixture with a chemical thermometer and **notice the condition of the water in the test tube.**

379. Latent Heat of Solution.—During the process of solution, as well as during fusion, heat is rendered latent. *Hence, the solution of a solid involves a diminution of temperature.*

(*a.*) A cup of coffee is cooled by sweetening it with sugar and a plate of soup is cooled by flavoring it with salt.

380. Freezing Mixtures.—*The latent heat of solution lies at the foundation of the action of freezing mixtures.* For example, when ice is melted by salt and the water thus formed dissolves the salt itself, the double liquefaction requires a deal of heat which is often furnished by the cream in the freezer.

(*a.*) The freezing mixture most commonly used consists of one

weight of salt and two weights of snow or pounded ice. The mixture assumes a temperature of —18° C., which furnished the zero adopted by Fahrenheit.

(*b.*) Persons who sleep in cold chambers sometimes notice that as soon as they touch a pitcher of water that has been standing in the room over night, the water quickly freezes. If a particle of ice be dropped into the water, the same result follows. We may say that, in this condition, liquids have a tendency to become solid and are restrained only by the difficulty of making a beginning.

Experiment 184.—Surround with a freezing mixture, a small glass vessel containing water and a mercury thermometer. The temperature of the water may be reduced to —10° C. or —12° C. without freezing the water. A slight movement of the thermometer in the water starts the freezing and **the temperature quickly rises to 0° C.**

Experiment 185.—Dissolve two weights of Glauber's salt in one weight of hot water, cover the solution with a thin layer of oil and allow to cool, in perfect quiet, to the temperature of the room. By plunging a thermometer into the still liquid substance, solidification (crystallization) is started and **the temperature rapidly rises.** Dr. Arnott found that this experiment was successful after keeping the solution in the liquid condition for five years.

Experiment 186.—To three weights of quicklime, add one weight of water. **The water will be completely solidified in the slaking of the lime with remarkable manifestations of heat.** Carts containing quicklime have been set on fire by exposure to heavy rains.

381. Solidification.—Solidification signifies the passage from the liquid to the solid condition. *During solidification, there is an increase of temperature.*

The heat energy, being no longer employed in doing the work of maintaining liquidity, is reconverted into sensible heat.

Experiment 187.—Pour a teaspoonful of sulphuric ether into the palm of the hand, being sure that there is no flame near to ignite the inflammable vapor of the ether. As the liquid evaporates, **notice that the hand is furnishing the heat needed to perform the work of vaporization.**

Experiment 188.—Wet a block of wood and place a watch crystal upon it. A film of water may be seen under the central part of the glass. Half fill the crystal with sulphuric ether and rapidly evaporate it by blowing over its surface a stream of air from a small bellows. So much heat is rendered latent in the vaporization that **the watch crystal is firmly frozen to the wooden block.**

FIG. 184.

Experiment 189.—Nearly fill the porous cup of a Grove or Bunsen cell (§§ 262, 263) with water at the temperature of the room. As the water evaporates at the surface of the porous cell, the **water in the cell becomes cooler,** heat having been withdrawn for the work of vaporization. After the lapse of 15 or 20 minutes, use a chemi-

cal thermometer to determine the temperature of the water. In this way, water is often cooled in tropical regions.

Experiment 190.—In a vessel of sulphuric ether, place a test tube containing water. Force a current of air through the ether. (Fig. 184.) Rapid evaporation is thus produced and, in a few minutes, **the water is frozen.**

382. Latent Heat of Vaporization.—The vaporization of a liquid is accompanied by the disappearance of a large quantity of heat and, frequently, by a diminution of temperature. There is a change of sensible into latent heat; of kinetic into potential energy. We may represent the vaporization of water as follows:

Steam at 100° C. = water at 100° C. + latent heat of steam.

383. Condensation of Gases.—Gases may be condensed by union with some liquid or solid, by cold or by pressure. It has been recently shown that any known gas may be liquefied by cold and pressure. In any case, *the condensation of a gas renders sensible a large amount of heat.*

(*a.*) When a gas that has been condensed is allowed to expand under such circumstances that *it must do work* (*e.g.* forcing back the surrounding air), its temperature is lowered. Icicles have been formed by allowing condensed air charged with watery vapor to escape suddenly from the confining vessel. The rapid expansion of carbon dioxide ("carbonic acid gas") when a bottle of beer or champagne is opened, often produces a fog in the neck of the bottle. (See *Chemistry*, § 197.)

(*b*.) Carbon dioxide may be liquefied by great pressure. When this liquid escapes through a small orifice into the air, evaporation is so rapid that some of the dioxide is frozen in the form of a fine snow. This carbon dioxide snow dissolves in sulphuric ether and with it forms one of the most intense freezing mixtures known. By adding the evaporation of this mixture with an air pump, *Faraday obtained a temperature of −110° C.*

Experiment 191.—Mix a pound of ice-cold water (0° C.) with a pound of water at 80° C. Note the temperature of the mixture. **We have two pounds of water at 40° C.** The heat lost by the hot water in cooling 40 degrees was equal to the heat gained by an equal weight of water in warming 40 degrees—in fact it was identical with it.

Experiment 192.—Place a pound of melting ice (0° C.) in a pound of water at 80° C. When the ice is all melted, note the temperature of the water. **We have two pounds of water at 0° C.**

384. The Latent Heat of Water.—In Experiments 192 and 193, the heat which warmed one pound of water from 0° to 80° C. was used to melt a like weight of ice. Hence, by definition, the latent heat of water is 80° C. (or 144° F.).

The amount of heat required to melt a quantity of ice without changing its temperature is eighty times as great as the heat required to warm the same quantity of water one centigrade degree.

(*a*.) Because of this great latent heat of water, the processes of melting ice and freezing water are necessarily slow.

385. The Latent Heat of Steam.—The amount of heat necessary to evaporate one gram of water would suffice to raise the temperature of 537 grams of water 1° C. Hence, the latent heat of steam is 537° C. (or 967° F.).

The amount of heat required to evaporate a quantity of water without changing its temperature is 537 times as great as the heat required to warm the same quantity of water one centigrade degree.

(*a*.) When a gram of steam is condensed, 537 heat units (centigrade-gram-water) are liberated. In this, we see an explanation of the familiar fact that scalding by steam is so painfully severe.

(*b*.) Were it not for the latent heat of steam, when water reached its boiling point it would instantly flash into steam with tremendous explosion.

386. Problems and Solutions.—(1.) How many grams of ice at 0° C. can be melted by one gram of steam at 100° C.? One gram of steam at 100° C., in condensing to water at the same temperature, parts with all its latent heat, or 537 heat units. The gram of water thus formed can give out 100 more heat units. Hence, the whole number of heat units given out by the steam in changing to water at 0° C., the temperature at which it could no longer melt ice, is $537 + 100 = 637$.

Since it requires 80 heat units to melt one gram of ice, 637 heat units will melt as many grams as 80 is contained times in 637, which is 7.96. Therefore, the steam will melt 7.96 grams of ice.

(2.) How many pounds of steam at 100° C. will just melt 100 pounds of ice at 0° C.? To melt 100 pounds of ice, ($80 \times 100 =$), 8,000 heat units will be required. Each pound of steam can fur-

nish 637 heat units for the work required. $8{,}000 \div 637 = 12.55$, the number of pounds of steam.

(3.) What weight of steam at 100° C. would be required to raise 500 grams of water from 0° C. to 10° C.? Each gram of water will require 10 heat units; 500 grams of water will require 5000 heat units. Each gram of steam can furnish $(537 + 90 =)$ 627 heat units for the work required. $5000 \div 627 = 7.97$, the number of grams of steam.

Experiment 193.—Mix any convenient quantity of ice-cold water (0° C.) with the same quantity of water at a temperature of 30° C. Ascertain the temperature of the mixture; **it will be about 15° C.** If you used a kilogram of water in each case, the 15000 heat units lost by the warm water and the 15000 heat units gained by the cold water were identical.

387. Equality of Loss and Gain.—*A substance loses as much heat in cooling a given number of degrees as would be gained by a like quantity when warmed an equal number of degrees.*

Experiment 194.—Suspend a vessel containing 3 kilograms of mercury in boiling water until you are sure that it has the temperature of the water (100° C.) Quickly pour the mercury into one kilogram (or liter) of ice cold water, 0° C. The temperature of the mixture will be about 9° C.

The kilogram of water, in being warmed 9° C., gained 9000 heat units; consequently, the 3 kilograms of mercury in cooling 91° C., must have lost 9000 heat units, for our experiment has neither created nor destroyed any heat and, if it was neatly performed, but little was lost.

For each degree of change of temperature, the kilogram of water gained 1000 heat units; for each degree of change of temperature, one kilogram of mercury lost $\frac{9000}{91 \times 3} = 33$ heat units. **In other words, it takes about 30 times as much heat to warm a given**

weight of water one degree as it does thus to warm the same weight of mercury.

388. Definition of Specific Heat.—*The specific heat of a body is the ratio between the quantity of heat required to warm it one degree and the quantity of heat required to warm an equal weight of water one degree.*

(*a.*) It is very important to bear in mind that specific heat, like specific gravity, is a ratio ; nothing more nor less. The specific heat of water, the standard, is unity. The specific heat of iron is 0.1138 ; of copper, 0.0952 ; of tin, 0.0562 ; of lead, 0.0314 ; of bismuth, 0.0308 ; of ice, 0.5 and of steam, 0.48. These ratios will be the same for any given substance, whatever the thermal unit or thermometric scale adopted.

389. Heated Balls Melting Wax.—The difference between bodies in respect to specific heat may be roughly illustrated as follows : small balls of equal weight, made severally of iron, copper, tin, lead and bismuth are heated to a temperature of 180° or 200° C. by immersing them in hot oil until they all acquire the temperature of the oil. They are then placed on a cake of beeswax about

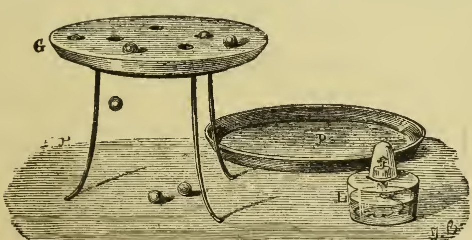

Fig. 185.

half an inch thick. The iron and copper will melt their way through the wax, the tin will nearly do so, while the lead and bismuth sink not more than half way through the wax. This shows that the iron or copper had more heat than an equal weight of lead or bismuth at the same temperature.

390. Specific Heat of Water.—*Water in its liquid form has a higher specific heat than any other substance except hydrogen.* For this reason, the ocean and lakes are cooled and heated more slowly than the land and atmosphere. They thus modify sudden changes of temperature, and give rise to land and sea breezes and to the well known fact that the climate of the sea-coast is warmer in winter and cooler in summer than that of inland places of the same latitude.

391. Recapitulation.—To be amplified by the pupil for review.

- **HEAT.**
  - UNITS.
  - ENERGY..
    - KINETIC=SENSIBLE HEAT.
    - Convertibility on "Critical occasions."
    - POTENTIAL=LATENT HEAT.
      - *Definition.*
      - *Of Fusion.*
      - *Of Solution.*
      - *Of Water.*
      - *Of Steam.*
      - *Freezing Mixtures.*
      - *Solidification.*
  - SPECIFIC.
    - DEFINITION.
    - ILLUSTRATION.
    - OF WATER.

EXERCISES.

1. Why does sprinkling the floor of a room on a warm day add to the comfort of the occupants of the room?

2. Does a dog's lolling his tongue on a summer day render him less warm? Explain.

3. Why do we often bathe a fevered brow with water or with a mixture of alcohol and water?

4. How many heat units are required to melt three pounds of ice? *Ans.*—432 units (pound-Fahrenheit).

5. How much heat is required to raise three pounds of ice-cold water to the boiling temperature? *Ans.*—540 units.

6. How much heat is required to vaporize 3 grams of boiling water? *Ans.*—1611 units (gram-centigrade).

7. How much heat is needed to melt and evaporate 3 pounds of ice? *Ans.*—3333 units (pound-Fahrenheit).

8. How much heat is needed to change a kilogram of ice at $-10°$ C. to water at $15°$ C.? (Take note of the specific heat of ice.) *Ans.*—722000 units.

SECTION IV.

MODES OF DIFFUSING HEAT.

Experiment 195.—Place one end of an iron poker into the fire. **The other end soon becomes too warm to handle.**

392. **Conduction.**—*The process by which heat is transferred from the hotter to the colder parts of a body, passing from one molecule to the next molecule, is called conduction of heat.* The propagation is very gradual and as rapid through a crooked as through a straight bar.

Experiment 196.—Instead of the iron poker of Experiment 195, use a glass rod or wooden stick. **The end of the rod may be melted or the end of the stick burned without rendering the other end uncomfortably warm.**

Experiment 197.—Thrust a silver and a German-silver spoon into the same vessel of hot water; **the handle of the former will become much hotter than that of the latter.**

Experiment 198.—Place a bar of iron and one of copper end to end so as to be heated equally by the flame of the lamp. Fasten small balls (or nails) by wax to the under surfaces of the bars at

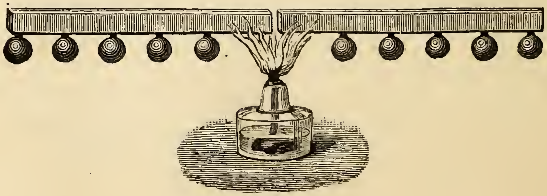

FIG. 186

equal distances apart. **More balls may be melted from the copper than from the iron.**

393. Difference in Conductivity.—These experiments show that some substances are good conductors of heat and that some are not.

(*a.*) Relative thermal conductivity of some metals:

Silver	100	Lead	9
Copper	74	Platinum	8
Brass	24	German silver	6
Iron	12	Bismuth	2

The above-named metals arrange themselves in the same order with reference to the conduction of electricity, silver being the best and bismuth the poorest. This relation suggests a similarity of nature between these two forms of energy.

Experiment 199.—Pass the tube of an air thermometer or of an inverted mercury thermometer through a cork in the neck of a funnel. Cover the thermometer bulb to the depth of about half an inch with water. Upon the water, pour a little sulphuric ether and ignite it. The heat of the flame will be intense enough to boil a small quantity of water held *over* it, but the **thermometer below will be scarcely affected.**

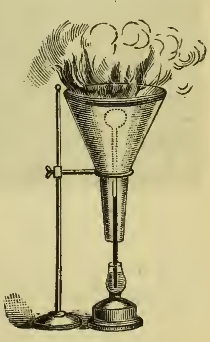

FIG. 187.

Experiment 200.—Fasten a piece of ice at the bottom of a glass test or ignition tube and cover it to the depth of several inches with water. Hold the tube obliquely and apply the flame of a lamp below the upper part of the water. **The water there may be made to boil without melting the ice below.** Instead of using ice and water, pack the tube full of moist snow if you can get it.

394. Conductivity of Fluids.—*Liquids and aeriform bodies are poor conductors of heat.* The surface of a liquid may be intensely heated without sensibly affecting the temperature an inch below. The conductivity of iron is about 80 times that of water; that of copper is about 500 times that of water. The conductivity of gases is probably less than that of liquids.

Experiment 201.—Drop a small quantity of cochineal or oak sawdust into a glass vessel containing water. Heat the water by a lamp placed below. **Notice the currents** indicated by the motion of the solid particles.

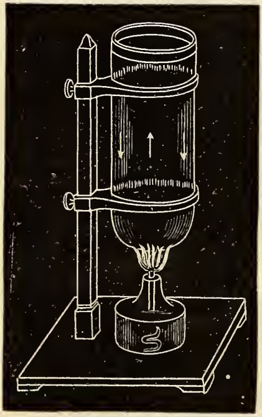

Fig. 188.

395. Convection. — Fluids (with the exception of mercury which is a metal) being poor conductors, they cannot be heated as solids generally are. Water, *e. g.*, must be heated *from below;* the heated molecules expand and rise while the cooler ones descend to take their place at the source of heat. *This method of diffusing heat, by actual motion of heated fluid masses, is called convection.*

396. Luminiferous Ether.—In the case of kinetic, mechanical energy, the rapid motion of bodies, *e. g.*, a vibrating guitar string, is partly carried off by the air in the shape of sound.

There is sufficient reason for believing that there is a medium pervading all space which carries off part of the invisible motions of molecules, just as the air carries off a portion of the motion of moving masses. This medium is called the luminiferous ether.

It is supposed to occupy intermolecular as well as interplanetary space, and to pass as freely between the particles of ordinary matter as the winds do between the trees of the forest.

Experiment 202.—Take a white-hot poker into a dark room. It emits heat and a white light. The light gradually becomes reddish and less bright, and finally fades from view as a dull red glow. Long after it has ceased to be visible, the poker continues to give heat to surrounding objects, as may be shown by holding the hand or face near it on any side, above or below. There has been a *continuous* change from the emission of white light and much heat to that of no light and less heat.

397. Radiant Heat.—The molecules of a heated body are in a state of active vibration. The motion of these vibrating molecules is communicated to the ether and transmitted by it, as waves, with wonderful velocity. Thus, when you hold your hand before a fire, the warmth that you feel is due to the striking of these ether-waves upon your skin; they throw the nerves into motion just as sound-waves excite the auditory nerve and the consciousness corresponding to this motion is what we call warmth.

Heat thus propagated by the ether, instead of by ordinary forms of matter, is called radiant heat.

(*a.*) From the last experiment, we naturally conclude that radiant heat and light are identical. Thorough experimental investigation has confirmed this conclusion. When the energy of the ether waves produces a certain effect upon the retina of the eye, we call it light; when it produces another effect upon the nerves of touch, we call it radiant heat. "Thus radiant heat is brought under the undulatory theory of light, which in its turn becomes annexed as a magnificent outlying province of the kinetic theory of heat." (§ 420.)

398. Radiation of Heat.—*The transferrence of heat from one body to another at a distance irrespective of the temperature of the intervening medium, is called the radiation of heat.*

399. Incident Rays.—When radiant heat falls upon a surface, it may be transmitted, reflected or absorbed. If transmitted, it may be refracted. Rock-salt crystal transmits nearly all, reflects very little, and absorbs hardly any. Polished silver reflects nearly all, absorbs a little, and transmits none. Lampblack absorbs nearly all, reflects very little, and transmits none.

Experiment 203.—Hold a pane of glass between the face and a hot stove. **Notice that the glass shields the face from the heat of the stove.** Next, hold the glass between the face and the sun. **Notice that the glass does not shield the face from the heat of the sun.**

400. Diathermancy.—*Bodies that transmit radiant heat freely are called diathermanous; those that do not, are called athermanous.* These terms are to heat, what *transparent* and *opaque* are to light. Rock salt is the most diathermous substance known.

401. Obscure and Luminous Heat.—Heat that is radiated from a non-luminous source, as from a ball heated below redness, is called *obscure heat;* while part of that radiated from a luminous source, as from the sun or from a ball heated to incandescence, is called *luminous heat.* Heat from a luminous source is generally composed of both luminous and obscure rays.

Glass, water or a solution of alum allows luminous heat rays to pass but absorbs nearly all of the heat rays from a vessel filled with boiling water. In other words, these substances are diathermanous for luminous rays but athermanous for obscure rays.

A solution of iodine in carbon di-sulphide transmits obscure rays but absorbs luminous rays. By means of these substances, luminous and obscure rays may be sifted or separated from each other.

Experiment 204.—Hold a spectacle-glass or a larger lens (§ 450) from an opera glass in the sunlight, perpendicular to the sun's rays. A point may easily be found below the lens where it is unusually warm. At this point, called the *focus*, hold the tip of a common friction match or a bit of gun cotton that has been blackened with lamp black or soot. **The concentrated rays of the sun will set fire to the easily combustible substance.** Gun cotton may be ignited at the focus of a lens made of ice.

Experiment 205.—Stand beside an open fire and let your assistant stand in front of the fire. Let him use a piece of bright tin with which to throw back the light of the fire into your face. **Notice that heat as well as light is thrown back,** your face feeling warmer.

402. Refraction and Reflection of Heat.—Heat rays may be bent from a straight line on entering and

leaving a body, as shown in Experiment 204. *This bending of the ray is called refraction.*

The refraction of obscure rays cannot be shown by a glass lens, since glass is athermanous for such rays. A rock-salt lens and a thermopile may be used for such an experiment. (See § 278.)

Radiant heat may be reflected like light. (See § 430.)

403. Change of Radiant into Sensible Heat.—Of all the rays falling upon any substance, only those that are absorbed are of effect in heating the body upon which they fall. The motion of the ether waves may be changed into vibrations of molecules of ordinary matter, and thus produce sensible heat but the same energy cannot exist in waves of ether and in ordinary molecular vibrations at the same time. Lamp-black is a remarkably good absorbent.

Experiment 206.—Provide two small tin cans of the same size and shape. You can get them for the asking. In the cover of each, make a hole through which you may pass the bulb of a chemical thermometer. Blacken the outside of one can with paint or candle soot. Fill both cans with hot water from the same vessel and, consequently, of the same temperature. At the end of half an hour, pass the bulb of the thermometer through the holes in the covers and ascertain the temperature of the water in each can. **It will be found that the blackened can has radiated its heat (or cooled) more rapidly than the other.**

404. Relations of Absorption, Reflection and Radiation.–*Good absorbents are good radiators and poor reflectors, and vice versa. The powers of absorption and radiation go hand in hand.* (§ 338.)

The radiating power of a body depends largely upon the nature of its surface; smoothing and polishing the surface increases reflecting power and diminishes absorbing and radiating powers; roughening and tarnishing the surface increase the absorbing and radiating powers and diminish the reflecting power.

405. Recapitulation.—To be amplified by the pupil for review.

DIFFUSION OF HEAT.

- CONDUCTION.
  - DEFINITION.
  - GOOD CONDUCTORS.
  - RELATION TO ELECTRIC CONDUCTION.
  - IN FLUIDS.
- CONVECTION.
- RADIATION.
  - RADIANT HEAT.
    - *Definition.*
    - *Mode of Travel.*
    - *Incidert Rays.*
      - Transmitted.. Sub-stances.
        - *Athemanous,*
        - *Diathemanous,*
      - Refraction.
      - Reflection.
      - Absorption.
    - *Luminous.*
    - *Obscure.*
    - *Effect on Temperature.*
    - *Relation of Radiators, Reflectors and Absorbers.*
  - *Luminiferous Ether.*

EXERCISES.

1. Why is a moist, cold atmosphere more severe than a dry atmosphere of the same temperature?

2. Why does fanning one's self on a warm day increase one's personal comfort?

3. Why is it that, in a cold room, some things seem colder than others?

4. (*a.*) Is a good conductor or a non-conductor better for keeping a warm body warm? (*b.*) For keeping a cold body cool?

5. How is heat transmitted through a crooked iron rod?

6. Is a good absorbent of heat better for radiation or for reflection of heat?

SECTION V.

THERMODYNAMICS.

406. Definition of Thermodynamics.—*Thermodynamics is the branch of science that considers the connection between heat and mechanical work.* It has especial reference to the numerical relation between the quantity of heat used and the quantity of work done.

407. Correlation of Heat and Mechanical Energy.—We know that heat is not a form of matter because *it can be created in any desired quantity.* We must continually remember that it is a form of energy. When heat is produced, some other kind of energy must be transformed. Conversely, when heat disappears, some other form of energy appears.

408. Heat from Percussion.—A small iron rod placed upon an anvil may be heated to redness by repeated blows of a hammer. (Experiment 169.) The energy of the moving mass is broken up, so to speak, and distributed among the molecules, producing the form of molecular motion that we call heat. The same transformation was illustrated in the kindling of a fire by the "flint and steel" of a century ago. The bullet is heated by its blow against the target and the water is warmer at the foot of Niagara than in the rapids above.

409. Heat from Friction.—Common matches are ignited and cold hands warmed by the heat developed by friction. It is said that some savages kindle fires by skillfully rubbing together well-chosen pieces of wood. A railway train is really stopped by the conversion of its motion into heat by means of the brakes. Examples of this change are matters of every-day experience. (Experiment 168.)

410. Heat from Chemical Action.—When coal is burned, the carbon and oxygen particles rush together with tremendous violence, energy of position being converted into energy of motion.

The molecular motions produced by this clashing of particles constitute heat and have a mechanical value.

411. Heating Powers.—If a given weight of carbon be burned, the heat of the combustion would warm about 8000 times that weight of water 1° C. In like manner, the combustion of a gram of hydrogen would yield more than 34000 heat units (gram-centigrade).

(*a.*) The following table shows the heating powers of several substances when burned in oxygen:

Hydrogen	34,462	Carbon	8,080
Petroleum	12,300	Alcohol (C_2H_6O)	6,850

(*b.*) The heating powers mentioned above may be adapted to Fahrenheit degrees by multiplying them respectively by $\frac{9}{5}$. As they stand, the numbers represent the number of times its own weight of water could be warmed 1° C. by burning the substance in oxygen.

412. First Law of Thermodynamics.—*When heat is transformed into mechanical energy or mechanical energy into heat, the quantity of heat equals the quantity of mechanical energy.*

413. Joule's Equivalent.—It is a matter of great importance to determine the numerical relation between heat and mechanical energy; to find the equivalent of a heat unit in units of work. This equivalent was first ascertained by Dr. Joule, of Manchester, England. His experiments were equal in number and variety to the importance of the subject. He showed that the mechanical value of the heat required to warm a given weight of water—

1° C., would lift the water..........	424 meters against gravity. 1390 feet " "
1° F., would lift the water............	772 " " "

Any weight unit may be used without changing the above values which should be remembered.

Referring to the first unit mentioned in § 376, we say that the mechanical value of a heat unit is 424 grammeters or 1390 foot-pounds.

Referring to the second unit there mentioned, we say that the mechanical value of the heat unit is 772 foot-pounds.

414. The Steam-Engine.—The steam-engine is a machine for utilizing the tension of steam. Its essential parts are a boiler for the generation of steam and a cylinder for the application of the tension to a piston.

415. Double-Acting Engine.—In a double-acting steam-engine, the steam is admitted to the cylinder alternately above and below the piston. This alternate admission of the steam is accomplished by means of a sliding-valve. The sliding-valve is placed in a steam-chest, *S*, which is fastened to the side of the cylinder, *C*.

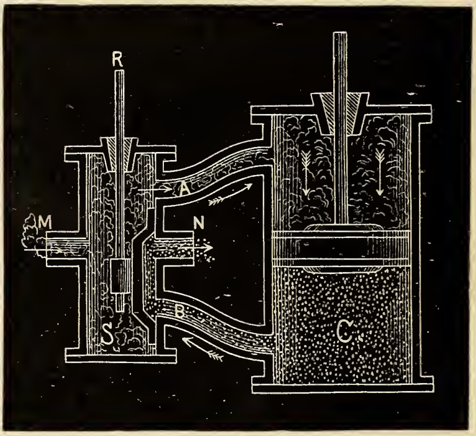

FIG. 189.

(*a*.) In the figure, the steam-chest is represented as being placed at a distance from the cylinder; this is merely for the purpose of making plain the communicating passages to and from the chest. Steam from the boiler enters at *M*, passes through *A* to the cylinder, where it pushes down the piston as indicated by the arrows in Fig. 189. The steam below the piston escapes by *B* and *N*.

(*b*.) As the piston nears the opening of *B* in the cylinder, the sliding-valve is raised, by means of the rod, *R*, to the position indicated in Fig. 190. Steam now enters the cylinder by *B* and

pushes up the piston. The steam above the piston escapes by A and N. As the piston nears the opening of A in the cylinder, the sliding-valve is pushed down by R and the process is thus repeated.

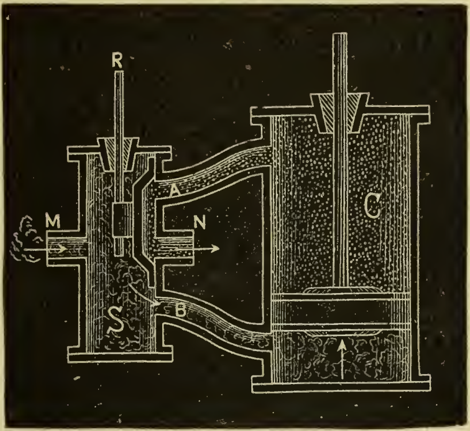

FIG. 190.

(c.) The piston-rod and the sliding-valve rod work through steam-tight packing-boxes. The piston is connected with a crank on the shaft of the engine, so that the to-and-fro motion of the piston produces a rotary motion of the shaft. Smoothness of motion is secured by attaching a heavy fly-wheel to the shaft of the engine. A little reflection will show that the fly-wheel also acts as an *accumulator of energy*.

416. Non-Condensing Engines.—When the steam is forced out at N (Fig. 190), it has to overcome an atmospheric pressure of 15 pounds to the square inch. Such an engine is known as a non-condensing engine. It may be recognized by the escape of steam in puffs.

It is generally a high-pressure engine. The railway locomotive is a high-pressure, non-condensing engine.

417. Condensing Engines.—The steam may be conducted from the exhaust pipe, N (Fig. 190), to a chamber called a condenser. Steam from the cylinder and a spray of cold water being admitted at the same time, a vacuum is formed and the loss of energy due to atmospheric pressure is avoided. Such an engine is known as a condensing, or low-pressure engine. Steamboat engines are generally condensing engines.

(*a*.) Low-pressure engines are always condensing engines. A low-pressure engine will do more work with a given amount of fuel than a high-pressure, non-condensing engine will, is less liable to explosion and causes less wear and tear to the machinery. But it must be larger, more complicated, more costly and less easily portable.

418. Heat and Work of Steam-Engines.—More heat is carried to the cylinder of a steam-engine than is carried from it.

The piston does work at every stroke and this work comes from the heat that disappears. Every stroke of the piston transforms heat energy into mechanical energy.

Careful experiments show that the heat destroyed and the work performed are in strict agreement with Joule's equivalent. With a given supply of fuel, the engine will give out less heat when it is made to work hard than when it runs without doing much work.

419. Recapitulation.—To be amplified by the pupil for review.

- THERMODYNAMICS.
  - DEFINITION.
  - MECHANICAL POWER CHANGED TO HEAT BY
    - PERCUSSION.
    - FRICTION.
  - ATOMIC ATTRACTION.
    - A SOURCE OF HEAT.
    - HEATING POWERS OF SEVERAL SUBSTANCES
  - LAW.
  - JOULE'S EQUIVALENT.
  - STEAM-ENGINES.......
    - ESSENTIAL PARTS.
    - DOUBLE ACTING.
    - CONDENSING.
    - NON-CONDENSING.
    - RELATION BETWEEN HEAT AND WORK.

EXERCISES.

1. If it were possible to convert heat into mechanical power without loss, how far would the heat given out by 1 gram of water in cooling 1° C. lift another gram of water against the force of gravity? Give your answer in meters and in feet.

2. How high would it lift 2 grams of water?

Ans.—212 *m.*, or 695 feet.

3. How high would it lift 2 grams of lead?

4. How high would the heat thus given out by a pound of water lift a pound weight?

5. How high would the heat thus given out by 10 pounds of water lift a 5 pound weight? *Ans.*—848 *m.*, or 2780 feet.

6. How high would the heat thus given out by 5 pounds of water lift a 10 pound weight?

7. If a pound of water falls 772 feet, how much will it be heated by the stopping of its motion?

8. If a 2 pound weight falls 772 feet, how much heat will be developed by the percussion when it strikes the ground?

9. How many heat units (gram-centigrade) must be transformed in order to raise 1000 grams to a height of 424 meters?

10. How many, thus to raise 2 kilograms? *Ans.*—2000.

11. How many grams of water can be heated from the freezing to the boiling temperature by the heat produced by burning 1 gram of hydrogen?

12. How many weights of water may be thus heated by burning 1 weight of pure coal (carbon)? *Ans.*—80.8.

13. If a good steam-engine utilizes only about 10 *per cent.* of the heat energy of its fuel, how many foot pounds of work can it do with a ton of coal that is *assumed* to be pure carbon?

Ans.—$2000 \times 8080 \times 1390 \times \frac{1}{10}$.

14. Would it do more work or less with the burning of a like weight of petroleum?

15. Can heat be destroyed? Can energy?

REVIEW QUESTIONS.

1. What three things determine the rapidity of vibration of a string?

2. (*a*.) Will sound waves pass through water? (*b*.) Through a vacuum?

3. What is in the upper part of a thermometer tube?

4. Upon what does the loudness of sound depend?

5. Why are spaces left between the ends of the rails in laying railway tracks?

6. Why is a gallon of alcohol worth more in cold than in warm weather?

7. Will a siphon work in a vacuum? Why?

8. Can you pump any water out of an air-tight cistern full of water? Explain.

9. Can you pump any water out of an air-tight cistern half full of water? Explain.

10. Construct a simple piece of apparatus to illustrate your answers to the last two questions.

11. Which seems colder, a windy or a still day, the temperature being the same? Why?

12. If there were no water on the earth, would the *differences* in temperature between day and night and between summer and winter be greater or less than they now are? Why?

13. Does heat *always* expand water?

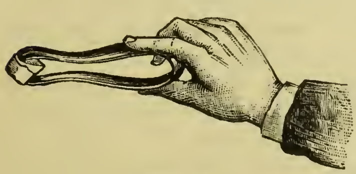

FIG. 191.

14. How can you heat water above 212 F.?

15. Do all solids and gases expand equally?

16. Show that the apparatus represented in Fig. 191 is a lever and tell of what class. Indicate the positions for *P*, *W* and *F*.

17. How does perspiration increase one's personal comfort in warm weather?

18. If a pound of water at 100° C. be added to a pound of water at 0° C., what will be the resulting temperature?

19. Fig. 192 represents a "dropping bottle." (*a.*) Why does air bubble up from the lower end of tube *a* when liquid drops from the lower end of *c*? (*b.*) Why does the liquid cease to drop when the finger closes the tube at *a*?

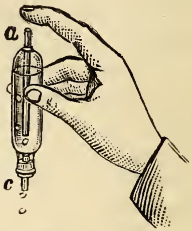

Fig. 192.

20. The "return ball" is a common toy made by fastening a wooden ball to the end of an elastic cord. When thrown from the hand, the cord being held by the free end, the ball returns and is caught in the hand. Does the motion of the ball resemble water waves or sound waves the more closely?

21. A centigrade thermometer records 33°. What will be the reading of a Fahrenheit thermometer under similar circumstances?

22. Show how the apparatus represented in Fig. 193 acts to obviate the trouble arising from the "boiling away" of the water in the basin.

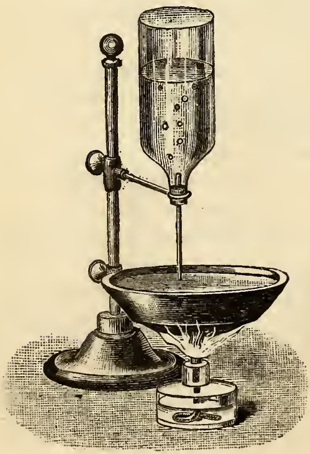

Fig. 193.

23. Describe the suction pump.

24. What is the cause of difference of pitch?

25. What is meant by the temperature of the maximum density of water?

26. What is meant by the absolute zero of temperature?

27. What is the ordinary medium for the transmission (*a.*) of sound? (*b.*) Of radiant heat?

28. Give the rule for finding the downward pressure of liquids caused by gravity.

29. What are ions?

30. A bullet is thrown downward with a velocity of 20 meters *per* second. What will be its velocity at the end of 4 seconds?

31. Fill with water a cup suspended by three cords. Turn the cup round and round, thus twisting together the cords. Leave the cup free to untwist the cords and water will fly from the edges of the cup as shown in Fig. 194. What physical law is thereby illustrated?

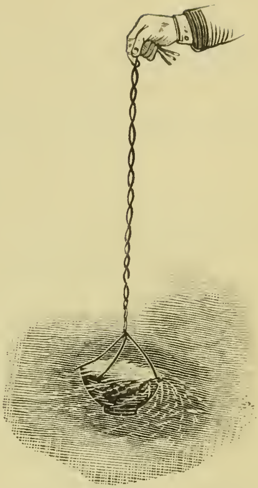

FIG. 194.

32. Note the temperature by the school-room thermometer. What is the velocity of sound now and here?

33. Define chemical change and give an illustration thereof.

CHAPTER IX.

LIGHT.

SECTION I.

THE NATURE, VELOCITY AND INTENSITY OF LIGHT.

420. What is Light?—*Light is the mode of motion that is capable of affecting the optic nerve. It is physically identical with radiant heat, the only difference, in any case, being one of wave length.* (See § 397.)

(*a.*) We have seen that the vibrations of air particles in a sound wave are to and fro in the line of propagation. In the case of radiant heat and light, the ether particles vibrate to and fro across the line of propagation. Vibrations in a sound wave are *longitudinal;* those of a heat or light wave are *transversal.*

421. Luminous and Non-Luminous Bodies.—Bodies that emit light of their own generating, as the sun or a candle, are called luminous. Bodies that merely diffuse the light that they receive from other bodies are said to be non-luminous or illuminated. Trees and plants are non-luminous.

422. Transparent, Translucent and Opaque Bodies.—Transparent bodies allow objects to be seen distinctly through them, *e. g.*, air, glass and water.

Translucent bodies transmit light but do not allow bodies to be seen distinctly through them, *e. g.*, ground glass and oiled paper.

Opaque bodies cut off the light entirely and prevent objects from being seen through them at all.

423. Luminous Rays.—*A single line of light is called a ray. The ray may, without considerable error, be deemed the path of the wave.*

424. Luminous Beams and Pencils.—A collection of parallel rays constitutes a beam; a cone of rays constitutes a pencil. The pencil may be converging or diverging.

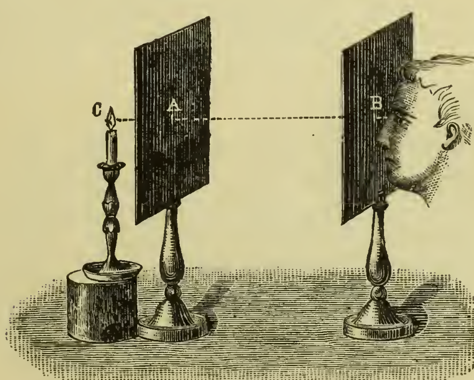

Fig. 195.

Experiment 207.—Provide two or three perforated screens and arrange them as shown in Fig. 195, so that the holes and a candle flame shall be in the same straight line. When the eye is placed

in this line behind the screens, light passes from the flame to the eye ; the flame is visible. A slight displacement upward, downward or sidewise of the eye, the flame or any screen, cuts off the light and **renders the flame invisible.**

Make the screen as follows : Prepare a piece of wood, $1\frac{1}{2} \times 2\frac{1}{2} \times 18$ inches, taking care that the edges are square. Saw it into six pieces, each three inches long. Prepare three pieces of wood, $3 \times 4 \times \frac{1}{8}$ inches. Place three postal cards one over the other on a board, and pierce them with a fine awl or stout needle, $\frac{1}{2}$ inch from the end and $1\frac{1}{2}$ inch from either side of the card. With a sharp knife pare off the rough edges of the holes, and pass the needle through each hole to make the edges smooth and even. Over the $\frac{1}{2} \times 3$ inch surface of one of the blocks, place the unperforated end of one of the postal cards and over this place one of the 3×4 inch pieces, so that their lower edges shall be even. Tack them in this position. Make thus two similar screens. The three screens, with a bit of candle three inches long, placed upon one of the remaining blocks, furnishes the material for the experiment above. Save the screens and three blocks for future use. (See Fig. 200.)

425. Rectilinear Motion of Light.—A medium is homogeneous when it has uniform composition and density. *In a homogeneous medium, light travels in straight lines.*

(*a.*) The familiar experiment of "taking sight" depends upon this fact, for *we see objects by the light which they send to the eye.* We cannot see around a corner or through a crooked tube.

Experiment 208.—Place a lighted candle about a yard from a white screen in a darkened room. (The wall of the room may answer for the screen.) Pierce a large pin-hole in a card and hold it between the flame and the screen. **An inverted image of the flame will be found upon the screen.**

Experiment 209.—Cover one end of a tube, 10 or 12 *cm.* long, with tinfoil; the other end with oiled paper. Prick a pin-hole in the tinfoil and turn it toward a candle flame. **An inverted image may be seen upon the oiled paper. The size of the image will depend upon the distance of the flame from the pin-hole.**

This apparatus rudely represents the eye (§ 473), the pin-hole corresponding to the pupil and the oiled paper to the retina. Almost any housekeeper will give you an empty tin can. Place it upon a hot stove just long enough to melt off one end, thrust a stout nail through the centre of the other end, cover the nail-hole with tinfoil and you will have the greater part of the apparatus.

426. Inverted Images.—If light from a highly-illuminated body be admitted to a darkened room through a small hole in the shutter and there received upon a white screen, it will form an inverted image of the ob-

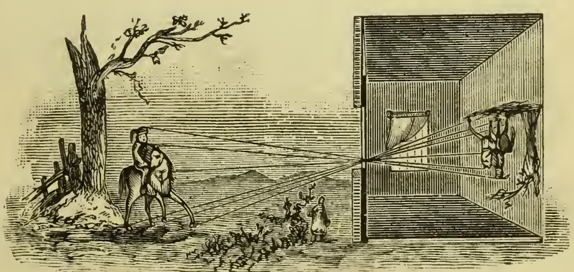

Fig. 196.

ject upon the screen. Every visible point of the illuminated object sends a ray of light to the screen. Each ray brings the color of the point which sends it and prints the color upon the screen. As the rays are

straight lines, they cross at the aperture; hence, the inversion of the image. The image will be distorted unless the screen be perpendicular to the rays. The darkened room constitutes a *camera obscura*. The image of the school playground at recess is very interesting and easily produced.

427. Velocity of Light.—*Light moves with a velocity of about 186,000 miles per second.*

(*a.*) It would require more than 17 years for a cannon-ball to pass over the distance between the sun and the earth; light makes the journey in 8 min. 18 sec. For the swiftest bird to pass around the earth would require three weeks of continual flight; light goes as far in less than one-seventh of a second. *For terrestrial distances, the passage of light is practically instantaneous* (§ 325).

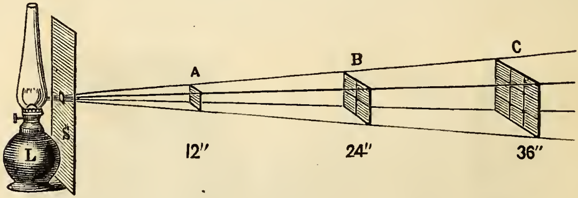

Fig. 197.

Experiment 210.—Let a candle or lamp at *L*, (Fig. 197) be the source of light; *S*, a cardboard screen with a small perforation at the level of the flame; *A*, a screen one inch square and a foot from *S*; *B*, a screen two inches square, two feet from *S*; *C*, a screen three inches square, three feet from *S*. It will easily be seen that *A* will cut off all the light from *B* and *C*. If *A* be removed, the quantity of light which it received, no more and no less, will fall upon *B*. If now *B* be removed, the quantity of light which previously illuminated *A* and *B* will fall upon *C*.

We thus see the same quantity of light successively illuminating one, four and nine square inches. One square inch at B will receive one-fourth, and one square inch at C will receive one-ninth as much light as one square inch at A. The light being spread over a greater surface is correspondingly diminished in intensity.

428. Effect of Distance upon Intensity.—*The intensity of light received by an illuminated body varies inversely as the square of its distance from the source of light.*

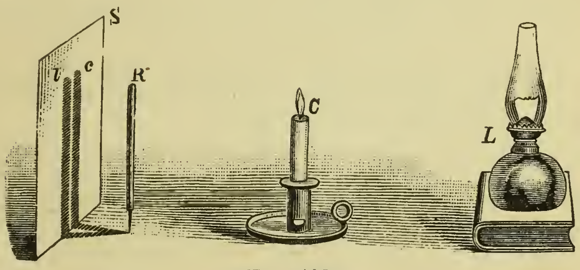

FIG. 198.

(a.) This principle is applied in photometry or the measurement of light. A simple photometer is represented in Fig. 198. S is a screen of white paper or cardboard; R is a small rod placed upright a few inches from S (a cheap pen and pen-holder or a lead pencil held by a bit of wax on the table will answer). The flame of the candle and that of the lamp should be at the same level; the flat lamp-wick should stand diagonally to the screen.

Place the candle about 20 inches from S and move L about until the two shadows upon S just touch and *are of equal darkness*. The candle and the lamp are now throwing equal amounts of light upon S.

If the distance from S to L be twice that from S to C, then S is four times as powerful a light as C; if the distance be three times as far, L is nine times as powerful. If C be 20 inches from S and L be 65 inches, then L is $\frac{65 \times 65}{20 \times 20}$ times as powerful as C.

(*b*.) Another method is to use a screen of paper with a grease spot in its centre. If this spot be viewed from the side toward the light, it will appear darker than the rest of the screen; if viewed from the other side, it will appear brighter. Place the two lights to be compared on opposite sides of the screen so that they shall be in the same straight line with the centre of the grease spot.

Move one light toward or from the screen *until the grease spot is invisible;* the two sides of the screen are then equally illuminated.

Find the distance of each light from the screen; square it; divide the greater square by the less: the quotient will be the ratio between the intensities of the two lights.

NOTE.—In either of these methods of photometry (light measuring), there should be no light falling on the screen except what comes from the two lights being compared.

429. Recapitulation.—To be amplified by the pupil for review.

LIGHT........
- DEFINITION.
- TRANSPARENCY OF BODIES.
- LUMINOUS... ....
  - BODY.
  - RAY.
  - BEAM.
  - PENCIL.
- RIGHT LINE MOTION.
- INVERTED IMAGES.
- VELOCITY.
- INTENSITY.

EXERCISES.

1. Do waves of light resemble sound waves more or less than they do water waves? Explain.

2. How does light differ from radiant heat?

3. What is a sunbeam?

4. Explain the formation of inverted images.

5. If the sun were blotted out of existence, how long would it be before the earth would be wrapped in darkness?

6. If the moon were twice as far from the earth as it is, what would be the effect upon the brilliancy of moonlight?

7. An electric lamp 100 ft. north of me and one 200 feet south of me illuminate opposite sides of a sheet of paper in my hand and render invisible a grease spot on the paper.

(*a.*) Which lamp is giving the more light to the paper?

(*b.*) How do the luminous powers of the lamps compare?

8. What is the difference between a luminous and an illuminated body?

9. An opaque screen, 3 inches square, is held 12 inches in front of one eye; the other eye is shut; the screen is parallel with a wall 100 feet distant. What area on the wall may be concealed by the screen?

10. A "standard" candle (burning 120 grains of sperm *per* hour) is 2 feet from a wall, a lamp is 6 feet from the wall. They cast shadows of equal intensity on the wall. What is the "candle power" of the lamp?

SECTION II.

REFLECTION OF LIGHT.

Note.—The heliostat, or *porte-lumière,* is composed of one or more mirrors, by means of which a beam of light may be thrown in any desired direction. The instrument may be had of apparatus manufacturers at prices ranging from $12 upward. Directions for making one may be found in Mayer & Barnard's little book on "Light."

430. Reflection.—If a sunbeam enter a darkened room by a hole in the shutter, as at *A*, and fall upon a

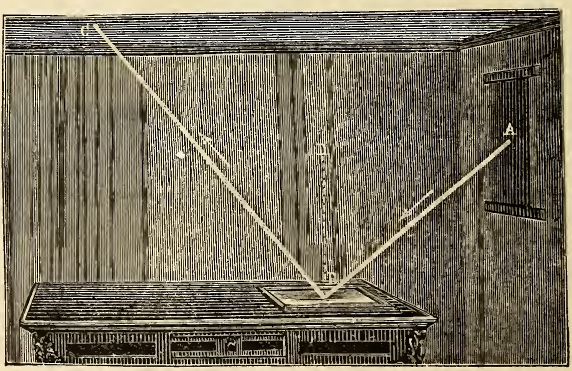

Fig. 199.

polished plane surface, as at *B,* it will be continued in a different direction, as toward *C.* *AB* is called the incident beam and *BC,* the reflected beam. The

incident and the reflected beams are in the same medium, the air.

A change in the direction of light without a change in its medium is called reflection of light.

Experiment 211. — Place two of the screens and the three extra blocks mentioned in Experiment 207 in position, as shown in Fig. 200. At the middle of the middle block, place a bit of window glass, painted on the underside with black varnish. On the blocks that carry the screens, place bits of glass, *n* and *o*, of the same thickness as the black mirror on the middle block.

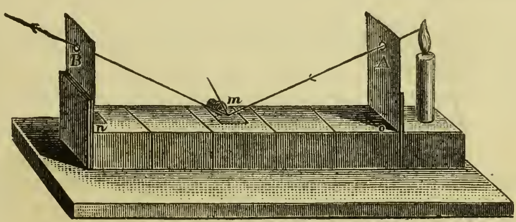

FIG. 200.

Place a candle flame near the hole in one of the screens, as shown in the figure. Light from the candle will pass through *A*, be reflected at *m* and pass through *B*. Place the eye in such a position that the spot of light in the mirror may be seen through *B*. Mark the exact spot in the mirror with a needle held in place by a bit of wax.

Place a piece of stiff writing paper upright upon *m* and *n*, mark the position of *B* and of *m*, and draw on the paper a straight line joining these two points. The angle between this line and the lower edge of the paper coincides with the angle *Bmn*. Reverse the paper, placing it upon *m* and *o*. It will be found that the same angle coincides with *Amo*. **Amo and Bmn being thus equal, the angle of incidence equals the angle of reflection.** (§ 57.)

Experiment 212.—Get a piece of looking glass, about an inch square. On the back of this little mirror, at the edges and in a triangular position, place three bits of soft wax each the size of a pea. Place the mirror on the wrist with one of the wax supports *on the pulse.*

Let this mirror replace the mirror shown in Fig. 199, hold the arm steady and watch the motions of the sun spot on the wall or ceiling. **They are like the beatings of the pulse which they make visible to the whole class.**

The reflected beam moves through an angle twice as great as does the mirror. If the pupil trying the experiment laughs, or becomes excited in any way, the change in the movement of the pulse becomes evident to all in the room.

431. Law of Reflection.—The reflection of light from a polished surface obeys the now familiar law : *The angle of incidence is equal to the angle of reflection.*

Experiment 213.—Let a beam of light fall upon a sheet of drawing paper in a darkened room; it will be scattered and illuminate the room. Let it fall upon a mirror; nearly all of it will be reflected in a definite direction and intensely illuminate only a *part of the room.*

Experiment 214.—Place, side by side upon a board, a piece of black cloth (not glossy), a piece of drawing paper and a piece of looking-glass. Allow a beam of sunlight to fall upon the cloth and **notice the absorption.** Let it fall upon the paper, and **notice the diffusion of the light** and its effects. Let it fall upon the looking-glass, and **notice the regular reflection** and its effects. Move the board so that the cloth, paper and glass shall pass through the beam in quick succession and notice the effects.

Experiment 215.—In the darkened room, place a tumbler of water upon a table; with a hand mirror, reflect the sunbeam down

into the water; the tumbler will be visible. Stir a teaspoonful of milk into the water and again reflect the sunbeam into the liquid; **the whole room will be illuminated by the diffused light,** the tumbler of milky water acting like a luminous body.

432. **Diffused Light.**—Light falling upon an opaque body is generally divided into three parts: the first is regularly reflected in obedience to the law above given; the second is irregularly reflected or diffused; the third is absorbed.

The irregular reflection is due to the fact that the bodies are not perfectly smooth, but present little protuberances that scatter the light in all directions and thus render them visible from any position. (Fig. 239.)

Light regularly reflected gives an image of the body from which it came before reflection; light irregularly reflected gives an image of the body that diffuses it. A perfect mirror would be invisible.

Luminous bodies are visible on account of the light that they emit; non-luminous bodies are visible on account of the light that they diffuse.

433. **Apparent Direction of Bodies.**—Every point of a visible object sends a cone of rays to the eye. The pupil of the eye is the base of the cone. *The point always appears at the place where these rays seem to intersect* (*i. e.*, at the real or apparent apex of the cone).

If the rays pass in straight lines from the point to the eye, the apparent position of the point is its real posi-

tion. If these rays be bent by reflection or in any other manner, *the point will appear to be in the direction of the rays as they enter the eye.* No matter how devious the path of the rays in coming from the point to the eye, this rule holds good.

Experiment 216.—Hold a printed page before a common mirror. Notice that each printed line is reversed ; each letter is turned side for side. "Look at yourself" in the mirror. The right hand of the image is opposite your left hand just as it would be if the image were another person facing you. **This reversing effect is called lateral inversion.**

Experiment 217.—Place a jar of water 10 or 15 *cm.* back of a pane of glass placed upright on a table in a dark room. Hold a lighted candle *at the same distance* in front of the glass. The jar will be seen by light transmitted through the glass. An image of the candle will be formed by light reflected by the glass. **The image of the candle will be seen in the jar, giving the appearance of a candle burning in water.** The same effect may be produced in the evening by partly raising a window and holding the jar on the outside and the candle on the inside.

434. **Plane Mirrors ; Virtual Images.**—If an object be placed before a mirror, an image of it appears behind the mirror. This is called a *virtual image.* All virtual images are optical illusions and are to be clearly distinguished from the *real images* to be studied soon.

Each point of the image will seem to be as far behind the mirror as the corresponding point of the object is in front of the mirror. Hence, images seen in still, clear water are inverted.

(*a.*) In Fig. 201, rays of light from A are reflected at B and B' and enter the eye at D. These rays *simply appear* to converge at A' which is, therefore, called the *virtual image* of A.

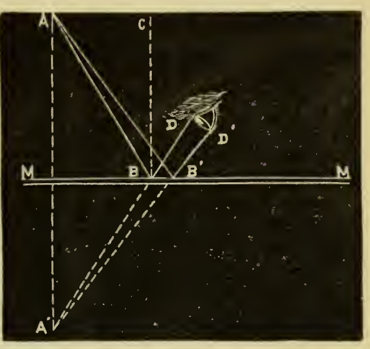

FIG. 201.

435. Concave Mirrors.—A spherical, concave mirror may be considered as a small part of a spherical shell with its inner surface highly polished. Let MN (Fig. 202) represent the section of such a concave, spherical mirror and C, the centre of the corresponding sphere. C is called the *centre of curvature*; A is the centre of

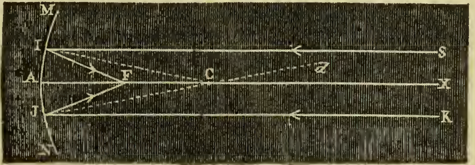

FIG. 202.

the mirror. A straight line drawn from A through C, as ACX, is called the *principal axis* of the mirror. A straight line drawn from any other point of the mirror through C, as JCd, is called a *secondary axis*. The point, F, midway between A and C, is called the *principal focus*. The distance, AF, is the *focal distance* of the

mirror; the focal distance is, therefore, one-half the radius of curvature. The angle, MCN, is called the *aperture* of the mirror.

(*a*.) It should be borne in mind that radii drawn from C to points in the mirror, as I and J, are perpendicular to the mirror at these points. Thus, the angles of incidence and of reflection for any ray may be easily determined.

436. Effect of Concave Mirrors.—*The tendency of a concave mirror is to make incident rays converge more or diverge less.*

437. The Principal Focus.—A focus is the point toward which rays converge. All incident rays parallel to the principal axis of a concave mirror will, after reflection, converge at the principal focus. *The principal focus is the focus of rays parallel to the principal axis.*

The rays will be practically parallel when their source is at a very great distance, *e.g.*, the sun's rays. Solar rays coming to the earth do not diverge a thousandth of an inch in a thousand miles.

438. Conjugate Foci.—Rays diverging from a luminous point in front of a concave, spherical mirror and at a distance from the mirror greater than its focal distance, will converge, after reflection, at another point. Rays diverging from B will form a focus at b. (Fig. 203.) Rays diverging from b would form a focus at B. Two such points are called *conjugate foci*.

Conjugate foci are two points so related that each forms the image of the other.

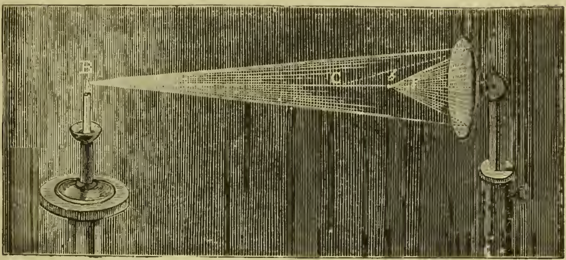

FIG. 203.

Experiment 218.—In a dark room, hold a candle between the eye and the concave side of a bright silver spoon held a little ways in front of the face. **Notice that the inverted image of the flame is in front of the spoon.**

Place the spoon between the flame and your face but so as to allow the face to be illuminated by the candle. **Notice the image of the observer.**

439. Projection of Real Images by Concave Mirrors.—The real image formed by a concave mirror may be rendered visible by projecting it upon a screen. In a darkened room, let a candle flame be placed in front of a concave mirror, at a distance from it greater than the focal distance and less than the radius of curvature of the mirror. Incline the mirror so that the flame shall not be on the principal axis. Place a paper screen at the conjugate focus of any point in the luminous object. The proper position for the screen may easily be found by trial. Shield the screen from the *direct* rays of the flame by a card painted black. The inverted image may be seen by a large class. (Fig. 204.)

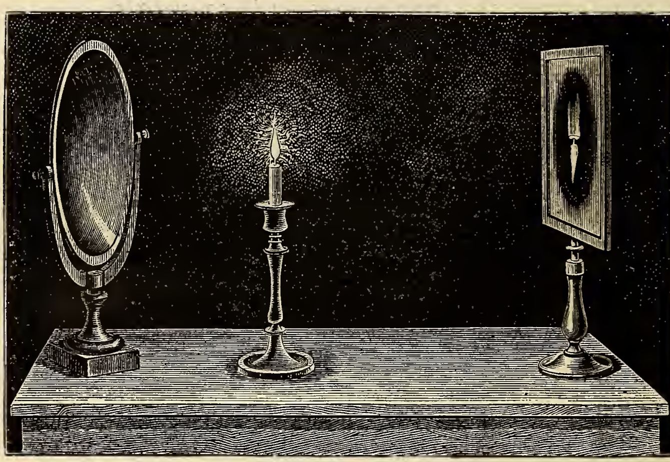

FIG. 204.

If the image fall between the mirror and the candle, as it will if the candle be at a distance from the mirror greater than the radius of curvature, the screen should be quite small. The image of any powerfully illuminated object may thus be produced, as shown in Fig. 205.

In both of these cases, the reflected rays *actually converge* on the screen; these images are, therefore, called *real images* to distinguish them from virtual images.

Experiment 219.—Hold the convex side of a bright silver spoon toward you and bring the spoon and a candle into the positions described in Experiment 218. **Notice that the erect image of the flame is back of the spoon.**

Place the spoon between the flame and your face but so as to allow the face to be illuminated by the candle. **Notice the image of the observer.**

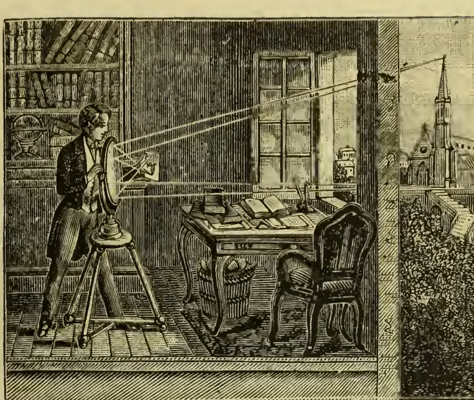

Fig. 205.

440. Convex Mirrors.—In convex mirrors, the images are virtual, erect and smaller than their objects.

441. Recapitulation.—To be amplified by the pupil for review.

REFLECTION OF LIGHT.
- DEFINITION.
- LAW.
- REGULAR ...
  - MIRRORS.
    - *Plane.*
    - *Concave.*
    - *Convex..*
    - *Concave.* and *Convex..* — Curved.
      - *Centre of Curvature.*
      - *Axes....*
        - *Principal.*
        - *Secondary.*
  - FOCI ....
    - *Definition.*
    - *Real.*
    - *Virtual.*
    - *Principal.*
    - *Conjugate.*
  - IMAGES..
    - *Real.*
    - *Virtual.*
    - *Erect.*
    - *Inverted.*
- IRREGULAR.
- APPARENT DIRECTION OF OBJECTS.

EXERCISES.

1. Given three points, A, B and C, not in a straight line. Show, by a diagram, how you would place a plain mirror at C so that light proceeding from A shall be reflected to B.

2. If you hold a sheet of paper with a greased spot on it between you and the light, the spot will look lighter than the rest of the sheet. Why is this?

3. If you hold the sheet in front of you when you are turned away from the light, the spot will look darker than the rest of the sheet. Why is this?

4. (*a.*) Is the image formed by a convex mirror real or virtual? (*b.*) Is it erect or inverted? (*c.*) Is it larger or smaller than the object?

5. What is the difference between real and virtual foci or images?

6. Why are the images seen in a pond of water inverted?

SECTION III.

REFRACTION OF LIGHT.

Experiment 220.—Procure a clear glass bottle with flat sides, about 4 inches (10 *cm.*) broad. On one side, paste a piece of paper, in which a circular hole has been cut. On this clear space, draw two ink-marks at right angles to each other, as shown in Fig. 206.

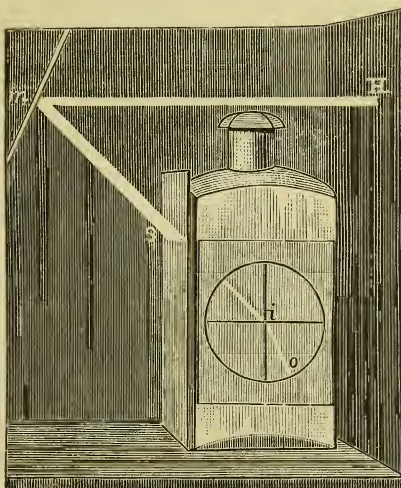

FIG. 206.

Fill the bottle with clear water up to the level of the horizontal ink-mark. Hold it so that a sunbeam coming through a hole in the shutter of a darkened room may pass through the clear sides of the bottle above the water and notice that the beam passes

through the bottle in a straight line. Raise the bottle so that the beam shall pass through the water and notice that the beam is still straight.

In a card, cut a slit about 5 *cm.* long and 1 *mm.* wide. Place the card against the bottle as shown in Fig. 206. With a mirror, reflect the beam through this slit at *S*, so that it shall fall upon the surface of the water at *i*, the intersection of the two ink marks. **Notice that the reflected beam is straight until it reaches the water but that it is bent as it enters the liquid.**

Experiment 221.—Put a small coin into a tin cup and place the cup so that its edge just keeps you from seeing the coin. A ray of light coming from the coin toward you must pass above the eye and thus be lost to sight. Pour water into the cup and **the coin will become visible.** The rays are bent down as they leave the water and some of them enter the eye.

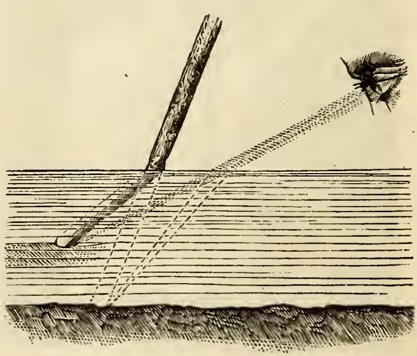

FIG. 207.

Experiment 222.—Notice that an oar or other stick half immersed in water seems bent at the water's surface, while rivers and ponds whose bottoms are visible are generally deeper than they seem to be. (Fig. 207.)

Experiment 223.—Place a bright spoon in a tumbler of water held at the level of the eye. Bring the bowl of the spoon to the side of the glass nearest you. Notice the appearance of the spoon. Move the spoon from you to the opposite side of the water in the tumbler. **Notice the changed appearance of the spoon.**

442. **Refraction.**—As a general thing, when a luminous beam falls upon a substance, some of the rays are turned back or reflected. Other rays enter the substance, being rapidly absorbed when the substance is opaque or freely transmitted when the substance is transparent. We have now to consider those rays that enter a transparent substance. Under some circumstances, such rays are bent.

This bending of a luminous ray when it passes from one medium to another is called refraction of light.

443. **Refraction Explained.**—Let us consider the passage of a ray of light through a glass prism, *ABC*.

The velocity of light is less in glass than in air and the direction in which a wave moves is perpendicular to the wave front.

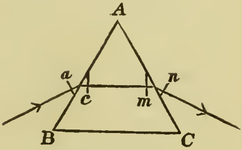

Fig. 208.

A wave approaches the side of the prism, *AB*. When at *a*, the lower end of the wave front first strikes the glass and enters it. This end of the wave moves more slowly than does the other, which is still in the air, and is continually retarded until the

whole wave has entered the glass. The wave front thus assumes the position shown at *c*.

The path of the wave being perpendicular to the front of the wave, this change of front causes a change in the direction of the ray which is thus refracted toward a perpendicular to the side, AB.

The wave now moves forward in a straight line until the top of the wave front strikes *AC*, the surface of the prism, as shown at *m*. The upper end of the wave front emerging first into the air gains upon the other end of the front, which is still moving more slowly in the glass. When the lower end emerges from the glass, the wave has the position shown at *n*.

This second change of front involves another change in the direction of the ray which is now refracted from the perpendicular.

(*a*.) Imagine a military company to be marching in "column of platoons," about 20 men abreast. Imagine them to be *obliged* to march in a direction perpendicular to the platoon front. The line of march lies through a triangular morass (*ABC* of Fig. 208). At *a*, the soldiers on the right of the first platoon enter the morass, and find that they cannot move as rapidly as they had previously done. The soldiers on the left of the platoon, maintaining their previous length and time of step, gain on the right of the platoon until they too enter the morass. But this gain has changed the alignment of the platoon to the position represented at *c*. Consequently, the line of march was bent or refracted at the point where the platoon passed from hard to soft ground. The velocity being lessened, the line was refracted *toward the perpendicular*.

In similar manner, at *m*, the left of the platoon first emerges from the morass and again gains upon the right flank. This changes the platoon front to the position represented at *n* and *refracts* the line of advance *from the perpendicular* at the point where the platoon emerges from the morass and is able to increase its velocity.

444. Laws of Refraction of Light.—(1.) *When light passes perpendicularly from one medium to another it is not refracted.*

(2.) *When light passes obliquely from a rarer to a denser medium it is refracted toward the perpendicular*, or toward a line drawn, at the point of incidence, perpendicular to the refracting surface.

(3.) *When light passes obliquely from a denser to a rarer medium, it is refracted from the perpendicular.*

Experiment 224.—Place the bottle shown in Fig. 206 upon several books resting upon a table and invert the card so that a beam of light reflected obliquely upward from a mirror on the table may enter through the slit near the bottom of the bottle, taking a direction through the water similar to the line *lA* of Fig. 212. **Notice that the sunbeam is turned downward at the upper surface of the water.**

Experiment 225.—Look into an aquarium in a direction similar to that represented by the line *lA* of Fig. 212, and you may often **see images of the fish or turtles near the surface of the water.**

Experiment 226.—Place a strip of printed paper in a test tube; hold it obliquely in a tumbler of water and look downward at the printing, which will be plainly visible. Change the tube gradually toward a vertical position, and soon **the part of the tube in the water takes a silvered appearance and the printing becomes invisible.** The disappearance of the reading is due to "total re-

flection." By dissolving a small bit of potassium dichromate in the water, the tube will have a golden instead of a silver-like appearance. Fill the test tube with water and **notice that the reading is visible,** the total reflection at the surface of the air in the tube being destroyed.

Experiment 227.—Place a bright spoon in a tumbler of water with the handle leaning from you. Hold the tumbler considerably above the level of the eye. Notice that you see not only the lower part of the spoon in the water but also *an image* of the shank of the spoon above the upper surface of the water as represented in Fig. 209. **The free liquid surface glistens and reflects as does a mirror.**

Fig 209.

445. Total Reflection.

—When a ray of light attempts to pass from a denser into a rarer medium, there are conditions under which the angle of refraction cannot be greater than the angle of incidence.

Under such circumstances, the ray cannot pass out from the denser medium but will be wholly reflected at the point of incidence.

Fig. 210 represents luminous rays emitted from *A*, under water, and seeking a passage into air. Passing from the perpendicular, the angle of refraction increases more rapidly than the angle of incidence until one ray is found

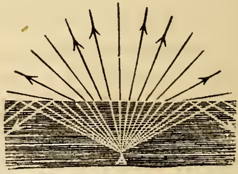

Fig. 210.

that emerges and grazes the surface of the water. Rays beyond this cannot emerge at all.

(*a.*) Fig. 211 represents a glass vessel partly filled with water. Mirrors are placed at *m* and *n*. In this way, a ray may be reflected at *m*, *n* and *o*, and refracted at *i*.

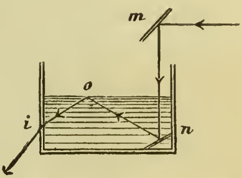

Fig. 211.

446. The Critical Angle.—Imagine a spherical flask (Fig. 212) half filled with water. A ray of light from *L* will be refracted at *A* in the direction of *R*. If the angle of incidence, *CAL*, be gradually increased, the angle of refraction will be gradually increased until it becomes 90°, when the ray will graze the surface of the water, *AM*. If the source of light be still further removed from *C*, as to *l*, the ray will be reflected to *r*.

For all media, there is an incident angle of this kind, called the critical or limiting angle, beyond which total internal reflection will take the place of refraction.

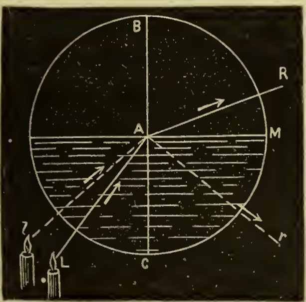

Fig. 212.

(*a.*) The reflection is called "total" because all of the incident light is reflected, which is never the case in ordinary reflection. Hence, a surface at which total reflection takes place constitutes the most perfect mirror possible.

447. Three Kinds of Refractors.—When a ray of light passes through a refracting medium, three cases may arise:

(1.) When the refractor is bounded by planes, the refracting surfaces being parallel. *The refractor is then called a plate.*

(2.) When the refractor is bounded by planes, the refracting surfaces being not parallel. *The refractor is then called a prism.*

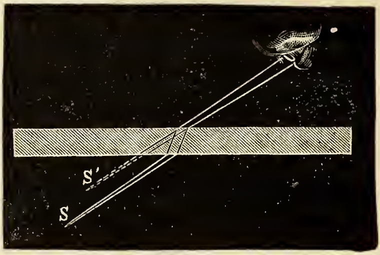

Fig. 213.

(3.) When the refractor is bounded by two surfaces of which at least one is curved. *The refractor is then called a lens.*

448. Plates.—When a ray passes through a plate, the refractions at the two surfaces are equal and contrary in direction. The direction of the ray after passing through the plate is parallel to its direction before entering. Objects seen obliquely through such plates appear slightly displaced from their true position. An object at S would appear to be at S' (Fig. 213).

449. Prisms.—A prism produces two simultaneous effects upon light passing through it; a change of direction and decomposition. The second of these effects will be considered under the head of dispersion (§ 463).

(*a.*) Let *mno* represent the section of a prism. A ray of light from *L* being refracted at *a* and *b* enters the eye in the direction

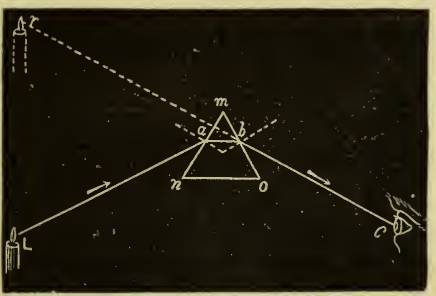

FIG. 214.

bc. The object being seen in the direction of the ray as it enters the eye (§ 433), appears to be at *r*.

(*b.*) An object seen through a prism seems to be moved in the direction of the *edge* that separates the refracting surfaces.

(*c,*) The refracted rays are bent toward the *side* that separates the refracting surfaces, or toward the thickest part of the prism.

450. Lenses.—The curved surfaces of lenses are generally spherical. With respect to their shape, lenses are of six kinds.

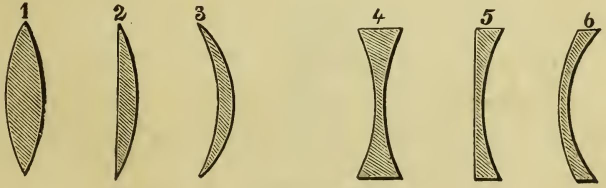

FIG. 215.

(1.) Double-convex, (2.) Plano-convex, (3.) Concavo-convex, or meniscus,	Thicker at the middle than at the edges.

The double-convex may be taken as the type of these.

(4.) Double-concave, (5.) Plano-concave, (6.) Convex-concave, or diverging meniscus,	Thinner at the middle than at the edges.

The double-concave may be taken as the type of these.

(*a.*) The effect of convex lenses may be considered as produced by two prisms with their bases in contact; that of concave lenses, by two prisms with their edges in contact.

(*b.*) The effects of lenses may be illustrated with spectacles or eye-glasses. The common magnifying glasses used in botanical study and for other purposes will answer. The larger lenses which may easily be removed from an opera-glass or a magic lantern may be made to furnish the apparatus needed for our present purposes. See description of "The Water Lens" and "The Fountain of Fire," in the little book of "Light" mentioned at the top of page 336.

451. Centre of Curvature; Principal Axis; Optical Centre.—A double convex lens, *ab*, (Fig. 216), may be described as the part common to two spheres which

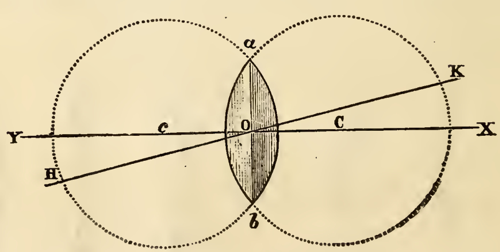

FIG. 216.

intersect each other. The centres of these spheres, *c* and *C*, are the *centres of curvature* of the lens. The straight line, *XY*, passing through the centres of curvature is the *principal axis* of the lens. In every lens there is a point, *o*, on the principal axis called the *optical centre.* It is generally at equal distances from the two faces of the lens. Any straight line, other than the principal axis, passing through the optical centre is a *secondary axis*, as *HK*.

Experiment 228.—Hold one of the large lenses of an opera glass in the sun's rays. **Notice the converging pencil formed by the rays** (after passing through the lens) as they pass through air made dusty by striking together two blackboard erasers. The focus and its distance from the lens may be seen. Measure this distance. Hold a similar lens by the other, face to face. **Notice that the rays after passing through both lenses converge more quickly**, lessening the distance of the focus from the lens.

452. Principal Focus.—*All incident rays parallel to the principal axis of a convex lens will, after two refractions, converge at a point called the principal focus.*

This point may lie on either side of the lens, according to the direction in which light moves; it is a real focus. Its distance from the lens is called the *focal distance.*

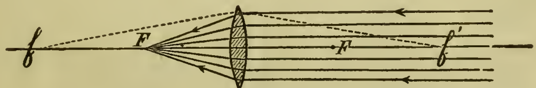

FIG. 217.

(*a.*) The position of the principal focus of a lens is easily determined. Hold the lens facing the sun. The parallel solar rays incident upon the lens will converge at the principal focus, F (Fig. 217). Find this point by moving a sheet of paper back and forth behind the lens until the sunny spot formed upon the paper is as bright and small as you can make it. Owing to the identity between heat rays and luminous rays, a convex lens is also a "burning glass."

(*b.*) Rays diverging from f, a point at twice the principal focal distance from the lens, will converge at f' at twice the focal distance on the other side of the lens. This may be shown by experimenting with a lens and candle-flame until the flame and its image upon a movable screen are at equal distances from the lens.

(*c.*) In such experiments, it is well to fit neatly the lens into a pasteboard or other opaque screen, to cut off from the screen all luminous rays other than those passing through the lens.

(*d.*) The foci situated at twice the principal focal distance are called *secondary foci.* They are conjugate foci.

Experiment 229.—Hold a magnifying-glass so as to see an object distinctly. Now move the object from the lens. The eye must be placed closer to the lens to secure distinct vision.

453. Conjugate Foci of Convex Lenses.—Rays

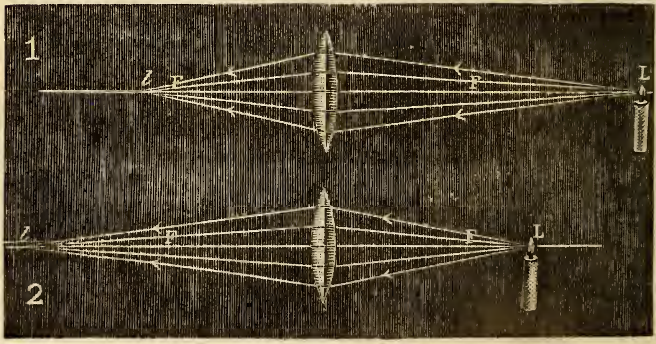

FIG. 218.

diverging from a luminous point in the principal axis at a small distance beyond the principal focus on either side of the lens will form a focus on the principal axis beyond the other principal focus. Thus, rays from L will converge at l (Fig. 218) ; conversely, rays from l will converge at L. The luminous point and the focus of its rays will lie in the same primary or secondary axis.

Two points thus related to each other are called conjugate foci; the line joining them always passes through the optical centre.

(*a.*) When the luminous point is at the focal distance, the refracted rays will be parallel (Fig. 219 [*1*]) and no focus will be formed.

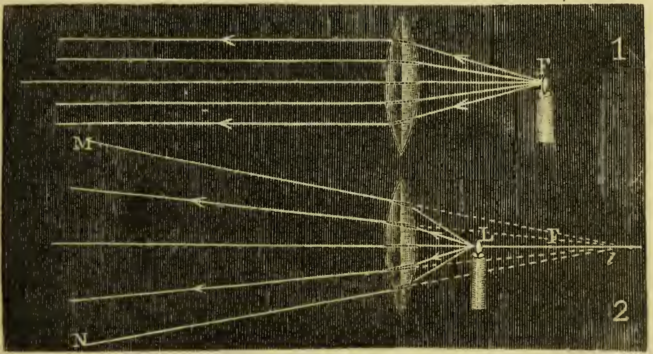

Fig. 219.

(*b.*) When the luminous point, L, is at less than the focal distance, the refracted rays will still diverge as if from a point, l, on the same side of the lens, more distant than the principal focus. (Fig. 219 [*2*]). This focus will be virtual.

(*c.*) Conversely, converging rays falling upon a convex lens will form a focus nearer the lens than the principal focus.

454. Images Formed by Convex Lenses.—The analogies between the convex lens and the concave mirror cannot have escaped the notice of the thoughtful pupil. Others will appear.

If secondary axes be nearly parallel to the principal axis, well-defined foci may be formed upon them, as well as upon the principal axis. A number of these foci may determine the position of an image formed by a lens.

455. Diminished Real Image.—*If the object, AB, be more than twice the focal distance from the convex lens, its image will be real, smaller than the object and inverted.* (Fig. 220.)

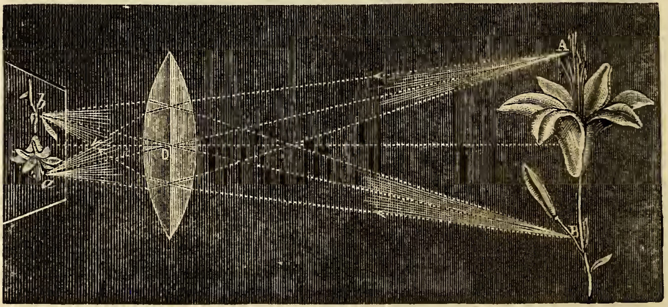

FIG. 220

Rays proceeding from A are focused at a upon the secondary axis, AOa; similarly with rays from B *and from all intermediate points.* Hence the image, *ab*.

456. Magnified Real Image.—*If the object be further from the lens than the principal focus, but*

at a distance less than twice the focal distance, the image will be real, magnified and inverted. (Fig. 221.)

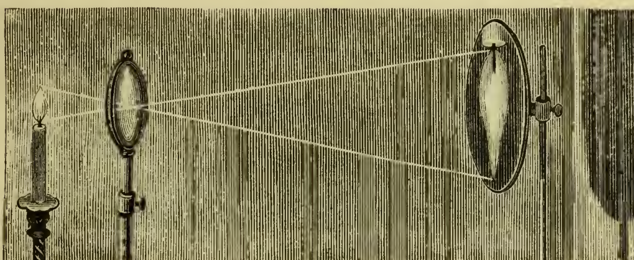

FIG. 221.

457. Virtual Image.—*If the object, AB, be placed nearer the lens than the principal focus, the*

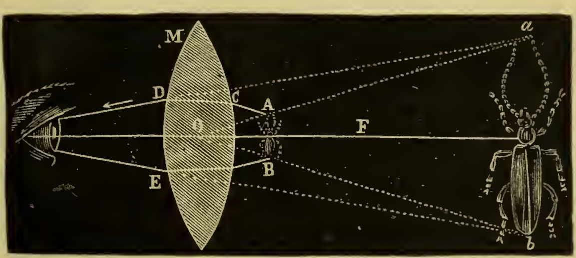

FIG. 222.

image will be virtual, magnified and erect. Rays from A appear to come from a; rays from B appear to come from b.

Experiment 230.—Repeat Experiment 228, using the eye-glasses or small lenses of an opera glass. **Notice that the refracted rays form a diverging pencil.**

458. Conjugate Foci of Concave Lens.—Rays from a luminous point at any distance whatever will be made more divergent by passing through a concave

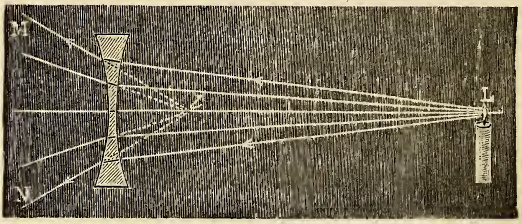

FIG. 223.

lens. Rays parallel to the principal axis will diverge after refraction as if they proceeded from the principal focus. In any case, the focus will be virtual and nearer the lens than the luminous point. In Fig. 223, the virtual image of L is at l, from which point the refracted rays appear to proceed.

459. Image formed by Concave Lenses.—*Images formed by a concave lens are virtual, smaller than the object and erect.*

460. Recapitulation.—To be amplified by the pupil for review.

REFRACTION OF LIGHT.

- DEFINITION.
- EXPLANATION.
- LAWS.
- CRITICAL ANGLE.
- REFRACTORS..........
  - PRISMS.
  - LENSES....
    - *Convex*..................
      - Foci.......
        - *Principal.*
        - *Conjugate.*
        - *Secondary.*
        - *Real.*
        - *Virtual.*
      - General Effect.
      - Images.....
        - *Real.*
        - *Virtual.*
        - *Erect.*
        - *Inverted.*
        - *Magnified.*
        - *Diminished.*
      - Analogous to Concave Mirrors.
    - *Centre of Curvature.*
    - *Axes*....
      - *Principal.*
      - *Secondary.*
    - *Optical Centre.*
    - *Concave*..................
      - Foci.......
        - *Principal.*
        - *Conjugate.*
        - *Virtual.*
      - General Effect.
      - Images.....
        - *Virtual.*
        - *Erect.*
        - *Diminished.*
  - PLATES.

EXERCISES.

1. (*a.*) What is refraction of light? (*b.*) State the laws governing the same. (*c.*) Give an illustrative diagram.

2. (*a.*) Name and illustrate by diagram the different classes of lenses. (*b.*) Explain, with diagram, the action of the burning-glass.

3. Explain total reflection.

4. Show, with diagram, how the secondary axes of a lens mark the limits of the image.

5. Using a convex lens, what must be the position of an object in order that its image shall be real, magnified and inverted?

6. Show, by a diagram, the course of a ray of light passing through the centre of a glass sphere.

7. Show, by a diagram, the course of a ray of light passing through a glass sphere at one side of the centre.

8. Draw the section of a prism and draw lines showing the path of a ray of light through it.

9. A cathetal prism (one whose section is an isosceles, right-angled triangle) may be used as a mirror. Draw a diagram showing how this may be done.

10. Draw diagrams showing the direction of rays of light before and after refraction by a double convex lens, the rays starting from a luminous point (*a.*) at the principal focus. (*b.*) On the principal axis between the principal and secondary foci. (*c.*) On the principal axis beyond the secondary focus. (*d.*) On the principal axis, between the lens and the principal focus.

SECTION IV.

CHROMATICS.—SPECTRA.

461. Other Results of Refraction.—Most luminous objects emit light of several kinds blended together. We must learn to sift these varieties one from the other and to deal with any one kind by itself.

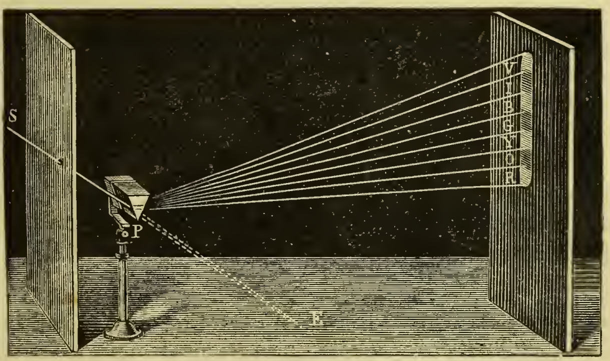

Fig. 224.

Experiment 231.—Admit a sunbeam through a very small opening in the shutter of a darkened room. The opening may be prepared by cutting a slit an inch (25 *mm.*) long and $\frac{1}{25}$ of an inch (1 *mm.*) wide in a card. See that the edges of the slit are smooth. Tack the slit over a larger opening in the shutter. If we look at the aperture from E (Fig. 224), we shall see the sun beyond. The path of the beam from S to E is made visible by the floating dust.

If a prism be placed in the path of the beam, as shown in the figure, the sides of the slit and edges of the prism being horizontal, the beam will be refracted upward. **If the refracted beam be**

caught upon a screen, it will appear as a band of differently colored light, passing very gradually from red at the bottom, through orange, yellow, green, blue and indigo to violet at the upper end of the beautifully colored band. By placing the slit in a vertical position and standing the prism on its end so that its edges will be parallel with the sides of the slit, the spectrum may be projected as a horizontal band.

The rays thus separated by the prism are identical with each other and with radiant heat except in the matter of wave length or (what amounts to the same thing) rapidity of vibration.

462. The Solar Spectrum.—*The colored band produced in Experiment 231 is called the solar spectrum.*

The initials of the names of these different colors form the meaningless word, VIBGYOR, which may aid the pupil in remembering these prismatic colors in their proper order.

463. Dispersion.—By looking at Fig. 224, it will be seen that the red rays have been refracted the least and the violet the most of all the luminous rays. *This separation of the differently colored rays by the prism is called the dispersion of light;* it depends upon the fact that rays of different colors are refracted in different degrees.

Experiment 232.—Let the rays that have been dispersed by a prism fall upon a convex lens as shown in Fig. 225. **They will be refracted to a focus and recombined to form white light.** A concave mirror may be used to reflect the rays to a focus instead of using the lens as above described.

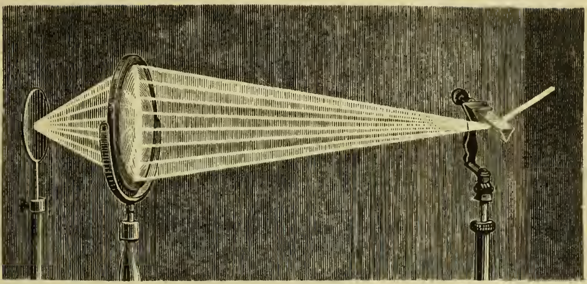

Fig. 225.

Experiment 233.—Make a "Newton's disc" of cardboard painted with the prismatic colors in proper proportion as indicated by Fig. 226. It is better to divide the surface given to each color into smaller sectors arranged alternately as shown in Fig. 227. You

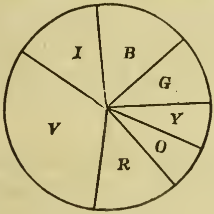

Fig. 226.

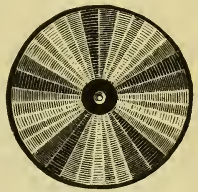

Fig. 227.

may paste sectors of properly colored paper upon the card-board instead of painting them. Cause this disc to revolve rapidly by means of the whirling table or by fastening it to a large top. **Notice that the colors are blended and that the disc appears grayish white.**

Experiment 234.—Hold a second prism near one that is used to produce a solar spectrum, the position of the second being inverted with reference to the first. If the dispersing prism be held as shown in Fig. 224 or 225, the second should be held with the refracting edge uppermost, the facing surfaces being parallel.

The dispersed rays emerging from the first prism will pass through the second. **The rays separated by the first will be again blended by the second and appear as white light.**

Experiment 235.—Hold a hand mirror near the dispersing prism so as to reflect the refracted rays to a distant wall or ceiling. Give to the mirror a rapid, angular motion so that the spectrum is made to move to and fro very quickly in the direction of its length. **The spectrum changes to a band of white light with a colored spot at each end.** The effect is due to what is known as the "Persistence of Vision," familiarly illustrated by the experiment of producing a ring of light by whirling a firebrand around a circle.

464. The Composition of White Light.—We have now shown, by both the processes of analysis and synthesis, that *white light is composed of the seven prismatic colors.* We have decomposed white light into its seven constituents and recombined these constituents into white light.

Experiment 236.—Paint three narrow strips of cardboard, one vermilion red, one emerald green, and the other aniline violet. Be sure that the coats are thick enough thoroughly to hide the cardboard. When dry, hold the red strip in the red of the solar spectrum; it appears red. Move it slowly through the orange and yellow; it grows gradually darker. **In the green and colors beyond, it appears black.** Repeat the experiment with the other two strips and carefully notice the effects.

Experiment 237.—Make a loosely wound ball of candle wick; soak it in a strong solution of common salt in water; squeeze most of the brine out of the ball; place the ball in a plate and pour alcohol over it. Take it into a dark room and ignite it. Examine objects of different colors, as strips of ribbon or cloth, by this yellow light. **Only yellow objects will have their usual appearance.**

465. Color of Bodies.—The color of a body is its property of reflecting or transmitting to the eye rays of a particular kind, the other rays being generally absorbed.

(*a.*) Properly speaking, color is not a property of matter, but of light. A ribbon is called red, but the redness belongs to the light, not to the ribbon. There would be more propriety in saying that the ribbon has *all the other colors* of the rainbow, because it keeps the others and reflects the red. If the red ribbon be placed in the green or blue of the spectrum, it will appear black because it receives no red rays to reflect.

466. The Rainbow.—The rainbow is due to refraction, reflection and dispersion of sunlight by water-drops. The necessary conditions are:

(1.) A shower during sunshine.

(2.) That the observer shall stand with his back to the sun, between the falling drops and the sun. (See *Elements of Natural Philosophy*, §§ 642–645.)

467. The Luminous Spectrum.—*The color of light depends only upon wave length or rapidity of vibration.* Color is to optics what pitch is to acoustics.

Red light has a wave length of $\frac{1}{39000}$ inch; violet light has a wave length of $\frac{1}{57500}$ inch. The wave lengths that correspond to the other colors are intermediate between these in value.

The shorter the wave, the more it is refracted (See Fig. 224). Of course, the wave length depends upon the rapidity of vibration of the molecule that produced the wave in the ether.

468. Other Properties of the Sunbeam.—We have decomposed a sunbeam, and thus produced the seven prismatic colors. But we must go still further. *Beyond the limits of the visible spectrum, in both directions, there are rays that do not excite the optic nerve,* the existence of which, however, may be easily proved. These visible and invisible rays differ only in respect to wave length. Some of these waves are so short and fall so rapidly that the optic nerve cannot respond to their vibrations. Others are so long and fall so slowly that the optic nerve cannot respond to their vibrations either. In either case, the rays are incapable of exciting vision.

469. Actinic Spectrum.—The actinic or chemical effects of sunlight are familiar to all. The sensitive paper of the photographer will remain unchanged in the dark; it will be quickly blackened in the light.

If a piece of paper, freshly washed in a solution of sulphate of quinine, be held successively in the different parts of the visible spectrum, it will be affected least in the red and most in the violet.

The maximum actinic effect will be found at a point beyond the violet, wholly outside the visible spectrum. We thus detect ultra-violet rays constituting an actinic spectrum.

A quartz prism is desirable for this experiment, as glass quenches most of the actinic rays.

470. Thermal Spectrum.—If a very delicate ther-

mometer or thermopile be successively placed in various parts of the spectrum, it will be found that the temperature is scarcely affected in the violet, but that there is a continual increase in temperature as the thermometer is moved toward the other end of the spectrum, it being quite marked in the red.

The greatest rise of temperature takes place beyond the red, wholly outside the visible spectrum. We thus detect ultra-red rays constituting a heat spectrum.

A rock-salt prism is desirable for this experiment, as glass absorbs most of the ultra-red rays.

Radiant heat differs from light only in wave length. All luminous rays have heating power; heat rays are luminous if their vibrations come at such a rate that the organ of sight can absorb their energy and respond with sympathetic vibrations (§ 338).

471. Recapitulation.—To be amplified by the pupil for review.

- **CHROMATICS.**
  - COMPLEXITY OF SUNBEAM........
    - ANALYSIS.
      - *Dispersion.*
        - By Prisms.
        - By Water Drops.
      - *Spectra....*
        - Luminous.
        - Actinic.
        - Thermal.
    - SYNTHESIS.
      - *By Lenses.*
      - *By Mirrors.*
      - *By Prisms.*
      - *By Persistence of Vision.*
  - COLOR OF BODIES.

EXERCISES.

1. What is the difference between the "diffusion of light" and "the dispersion of light"?

2. Why does a red body appear red?

3. Name the colors of the solar spectrum in their proper order, beginning with the one of least wave length.

4. To what quality of sound does color correspond?

5. Why does the moon look green when viewed through a piece of green glass?

6. You hold in your hand a red rose. You carry it into a room that is wholly dark. Has the rose then any color? Explain your answer.

7. Imagine a line 186,000 miles long extending from your eye toward the sun. Radiant energy (heat or light) will traverse such a line in a second (§ 427). Suppose that light from the sun is coming toward you. (*a.*) After the first wave reaches the far end of this line, how long will it take the same wave to reach you? (*b.*) If the light is red, how many such waves can lie on this line at once? (*c.*) How many such waves will enter your eye in a second?

8. You see a red ribbon. (*a.*) Does the ribbon reflect any light? (*b.*) How do you know? (*c.*) If it does, what is the color of the reflected light? (*d.*) Some of the sun's rays enter the ribbon; what is their effect?

9. "Converging" and "diverging" lenses are sometimes mentioned. What are they?

10. You see a rainbow. State the *threefold* work done upon a ray of light by each raindrop that contributes to the success of the exhibition.

SECTION V.

A FEW OPTICAL INSTRUMENTS.

472. Photographer's Camera.— The photographer's camera is nearly the same as the camera-obscura described in § 426. Instead of the darkened room we have a darkened box; instead of the simple hole in the shutter we have a convex lens, placed in a tube at *A*. (Fig. 228.)

(*a*.) A ground-glass plate is placed in the frame at *E*, which is adjusted so that a well-defined, inverted image of the object in front of *A* is projected upon the glass plate. This adjustment or "focusing" is completed by moving the lens and its tube by the toothed wheel at *D* until the object in front of *A* and the plate at *E* are at the conjugate foci of the lens at *A*. When the "focusing" is satisfactory, *A* is covered with a cloth, the ground-glass plate is replaced by a chemically-prepared sensitive plate, the cloth removed and the image projected on the plate. The light works certain chemical changes where it falls upon this plate and thus a more lasting image is produced. The many other processes involved in photography cannot be considered here.

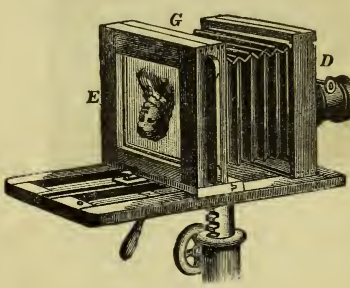

FIG. 228.

473. The Human Eye.—This most admirable of all optical instruments is a nearly spherical ball, capable

of being turned considerably in its socket. The outer coat, *S*, is called the *white of the eye.* Its transparent part in front, *C*, is called the *cornea.* The cornea is more convex than the rest of the eyeball. The cornea fits into the coat, *S*, as a watch crystal does into its case. Behind the coat, *S*, is a dark, opaque coat, *N*. Behind the cornea is a curtain, *I*, called the *iris.* It is colored and opaque; the circular window in its centre is called the *pupil.* The color of the iris constitutes the color of the eye. Back of the pupil is the *crystalline lens*, *L*, built of concentric shells (layer on layer, as in an onion) of varying density. Its shape is shown in the figure. This lens divides the eye into two chambers. The *anterior chamber* contains a limpid liquid called the *aqueous humor;* the *posterior chamber* contains a transparent jelly, *V*, called the *vitreous humor.*

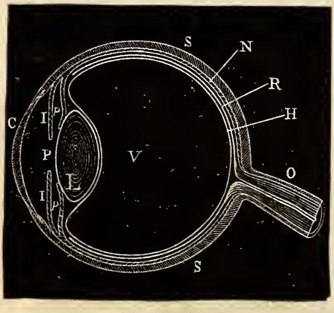

Fig. 229.

The cornea, aqueous humor, crystalline lens and vitreous humor are refracting media. Back of the membrane, *H*, which incloses the vitreous humor, is the *retina*, *R*, an expansion of the optic nerve.

The eye, optically considered, is simply an arrangement for projecting inverted, real images of visible objects upon a screen, R, made of nerve filaments. If the images thus formed be well defined and sufficiently luminous, the vision is distinct.

(*a.*) Objects are not seen distinctly unless the image falls directly upon the retina. If the image of a distant object falls in front of the retina, the person is said to be *near-sighted.* Near-sightedness may be relieved by the use of concave glasses.

If the image of a near object tends to fall back of the retina, the person is said to be *far-sighted.* Far-sightedness may be relieved by the use of convex glasses.

(*b.*) The eye of the common house-fly is said to have 4,000 lenses; that of some kinds of beetles is said to have 25,000, each with its own cornea and retina. "If each of these lenses forms a separate picture of each object, what an awful army of cruel giants must the beetle behold when he is captured by a schoolboy!"

474. Magnifying Glasses.—A magnifying glass, or simple microscope, is a convex lens, generally double-convex. The object is placed between the lens and its principal focus. The image is virtual, erect and magnified.

475. Compound Microscope.—The compound microscope consists of two or more convex lenses placed in a tube. One of these, *o*, called the object-glass or *objective*, is of short focus. The object, *ab*, being placed slightly beyond the principal focus, a real image, *cd*, magnified and inverted, is formed within the tube (§ 456).

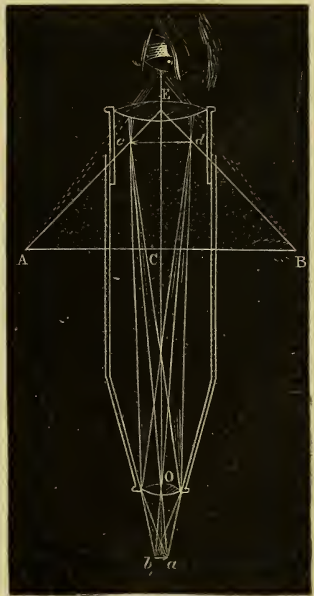

Fig. 230.

The other lens, *E,* called the *eye-glass,* is so placed that the image formed by the objective lies between the eye-glass and its focus. *AB* (Fig. 230) is a magnified, virtual image of the real image, formed by the eye-glass and seen by the observer.

476. Galilean Telescope; Opera Glass. — In the telescope attributed to Galileo, the objective, *O,* is a double convex and the eye-piece, *C,* is a double concave lens. The concave lens intercepts the rays before they have reached the focus of the objective.

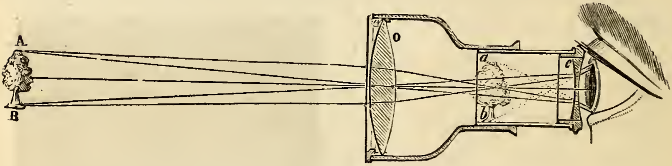

FIG. 231.

The rays from *A*, converging after refraction by *O*, are rendered diverging by *C*; they seem to diverge from *a*. In like manner, the image of *B* is formed at *b*. The image, *ab,* is erect and very near. An opera glass consists of two Galilean telescopes placed side by side.

477. Astronomical Telescope; Refractor.—Astronomical telescopes are of two kinds—refractors and reflectors. Fig. 232 represents the arrangement of the lenses and the direction of the rays in the refracting telescope. The object glass is of a large diameter that it may collect many rays for the better illumination of the image.

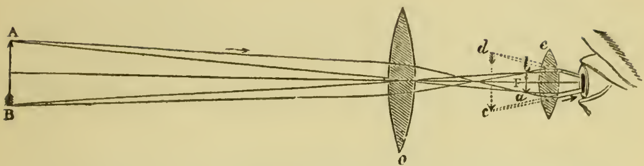

FIG. 232.

The inverted, real image, *ab*, formed by the objective, *O*, is magnified by the eye-piece, as in the case of the compound microscope. The visible image, *cd*, is a virtual image of *ab*, which is the real image of *AB*. The lenses are enclosed in a tube.

(*a*.) The largest refracting telescope (1884) is at the Pulkowa Observatory. Its object glass is 30 inches in diameter. A 36 inch object glass is making for the telescope of the Lick Observatory in California.

478. Reflecting Telescopes.—A reflecting telescope consists of a tube closed at one end by a concave

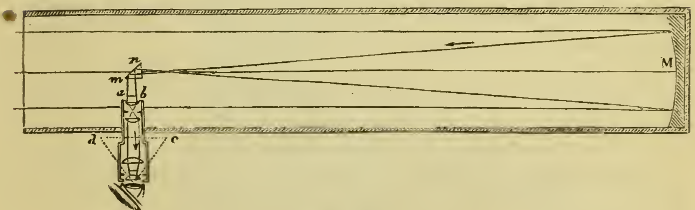

FIG. 233.

mirror, *M*, so placed that the image formed by it may be magnified by a convex lens used as an eye-piece. The rays from the mirror are reflected at *mn*, and a real

image formed at *ab*. This image is magnified by the glasses of the eye-piece and a virtual image formed at *cd*. The Earl of Rosse built a telescope with a mirror six feet in diameter and having a focal distance of fifty-four feet.

Experiment 238.—Reflect a horizontal beam of sunlight into a darkened room. In its path, place a piece of smoked glass on which you have traced the representation of an arrow, *AB*, (Fig. 234) or written your autograph. Be sure that every stroke of

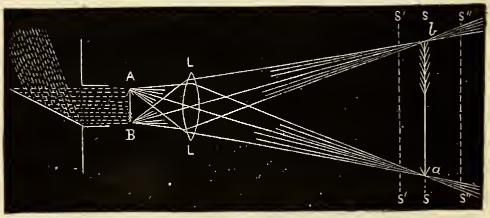

FIG. 234.

the pencil has cut through the lamp black and exposed the glass beneath. Place a convex lens beyond the pane of glass, as at *L*, so that rays that pass through the transparent tracings may be refracted by it as shown in the figure. It is evident that an image will be formed at the foci of the lens. If a screen, *SS*, be held at the positions of these foci, *a* and *b*, the image will appear clearly cut and bright. If the screen be held nearer the lens or further from it, as at S' or S'', the picture will be blurred.

479. Magic Lantern.—In the magic lantern (Fig. 235), a lamp is placed at the common focus of a convex lens (called the "condenser") in front of it and of a concave mirror behind it. The light is thus concentrated upon *ab*, a transparent picture, called the "slide." A system of lenses, *m*, is placed at a little more than its

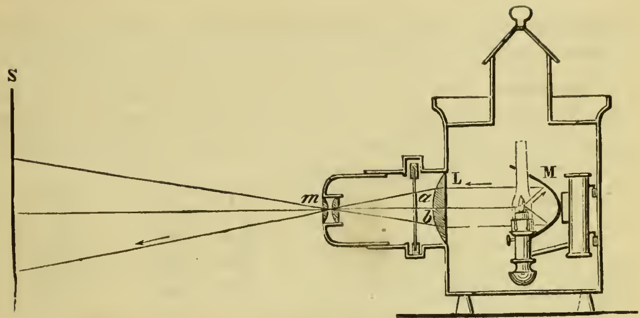

FIG. 235.

focal distance beyond the slide. A real, inverted, magnified image of the picture is thus projected upon the screen, *S*. The tube carrying *m* is adjustable, so that the foci may be made to fall upon the screen and thus render the image distinct. By inverting the slide, the image is produced right side up.

(*a*.) Directions for making a simple magic lantern may be found on page 84 of Mayer and Barnard's little book on *Light*. Fig. 236

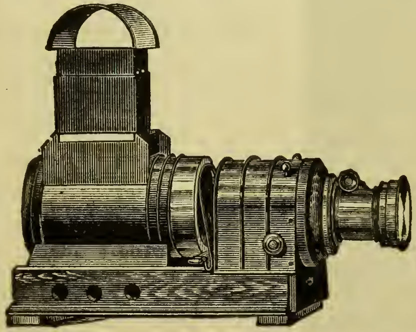

FIG. 236.

represents a very compact and efficient lantern, known as Marcy's Sciopticon and furnished by James W. Queen & Co., of Philadelphia.

Experiment 239.—Close the left eye and hold the right hand so that the forefinger shall hide the other three fingers. Without changing the position of the hand, open the left and close the right eye. The hidden fingers become visible in part.

Experiment 240.—Place a die on the table directly in front of you. Looking at it with only the left eye, three faces are visible, as shown at *A*, Fig. 237. Looking at it with only the right eye, it appears as shown at *B*.

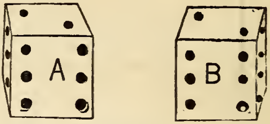

Fig. 237.

480. Stereoscopic Effects.—From the last two experiments, we see that *when we look at a solid, the images upon the retinas of the two eyes are different.* If, in any way, we combine two drawings, so as to produce images upon the retinas of the two eyes like those produced by the solid object, we obtain the idea of solidity.

Fig. 238.

481. The Stereoscope.—To blend these two pictures is the office of the stereoscope. Its action will be readily understood from Fig. 238. The diaphragm, *D*, prevents either eye from seeing both pictures at the same time. Rays of light from *B* are refracted by the half-lens, *E′*, so that they seem to come from *C*. In the same way, rays from *A* are refracted by *E* so that they also seem

to come from *C*. The two slightly different pictures, thus seeming to be in the same place at the same time, are successfully blended and the picture "stands out" or has the appearance of solidity. If the two pictures of a stereoscopic view were exactly alike, this impression of solidity would not be produced.

482. Recapitulation.—To be amplified by the pupil for review.

OPTICAL INSTRUMENTS.
- CAMERA
  - Obscura.
  - Photographer's.
- HUMAN EYE.
- MICROSCOPES
  - Simple.
  - Compound.
- TELESCOPES
  - Reflectors.
    - *Galilean.*
    - *Opera Glass.*
    - *Astronomical.*
  - Refractors.
- MAGIC LANTERN.
- STEREOSCOPE.

CONCLUSION.

ENERGY.

483. Varieties of Energy.—Like matter, energy is indestructible. We have already seen that energy may be visible or invisible (*i. e.*, mechanical or molecular), kinetic or potential. We have at our control at least eight varieties of energy.

(*a.*) Mechanical energy of position (visible, potential).
(*b.*) Mechanical energy of motion (visible, kinetic).
(*c.*) Latent heat (molecular, potential).
(*d.*) Sensible heat (molecular, kinetic).
(*e.*) Chemical separation (molecular or atomic; potential).
(*f.*) Electric charges (probably molecular, potential).
(*g.*) Electric currents (probably molecular, kinetic).
(*h.*) Radiant energy, thermal, luminous or actinic (molecular, kinetic).

484. Conservation of Energy.—The doctrine that, considering the universe as a whole, the *sum* of all the forms of energy is a constant quantity, is known as the *Conservation of Energy.*

$$a+b+c+d+e+f+g+h=\text{a constant quantity.}$$

This does not mean that the value of a is invariable; we have seen it changed to other varieties as b or d. We have seen heat changed to electricity and *vice versa,* and either or both changed to mechanical energy. It does not mean that the sum of these eight variable quantities in the earth is constant, for we have seen that energy

may pass from sun to earth, from star to star. *But it does mean that the sum of all these energies in all the worlds that constitute the universe is a quantity fixed, invariable.*

485. Correlation of Energy.—The expression *Correlation of Energy* refers to the convertibility of one form of energy into another. Our ideas ought, by this time, to be clear in regard to this convertibility. One important feature remains to be noticed. *Radiant energy can be converted into other forms, or other forms into radiant energy only through the intermediate state of absorbed heat.*

486. Recapitulation.—To be amplified by the pupil for review.

- **ENERGY.**
  - VISIBLE OR MECHANICAL.
    - *Of Position*, *Potential.* *e.g.*, Hanging Apple, Head of Water.
    - *Of Motion*, *Kinetic.* *e.g.*, Falling Apple, Flowing Water.
  - INVISIBLE OR MOLECULAR.
    - HEAT........
      - *Of Position*, *Potential.* *e.g.*, Latent Heat.
      - *Of Motion*, *Kinetic.* *e.g.*, Sensible Heat.
    - LIGHT........
      - *Of Motion*, *Kinetic.*
    - ELECTRICITY.
      - *Of Position*, *Potential.* *e.g.*, Charged Leyden jar, Battery with circuit broken.
      - *Of Motion*, *Kinetic.* *e.g.*, Leyden jar discharging; Battery with circuit closed.

GENERAL REVIEW.

1. (*a.*) Define science, matter, mass, molecule and atom. (*b.*) Define physics.

2. (*a.*) What are physical properties of matter? (*b.*) Define and illustrate two properties of matter.

3. Define solid, liquid and gas?

4. (*a.*) Give Newton's laws of motion. (*b.*) Give the law of reflected motion.

5. How may we measure distances by sound?

6. Upon what does the pitch of a sound depend?

7. Why do the rays of the evening sun come to us in curved lines?

8. How does distance effect the intensity of light?

9. What is an angle of reflection?

10. (*a.*) What is the general effect of a concave mirror? (*b.*) Of a concave lens?

11. Fig. 239 represents reflection of luminous rays from a rough surface. Draw a similar figure illustrating reflection by a plane mirror.

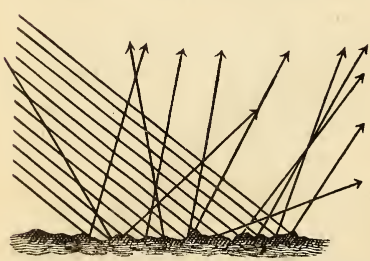

FIG. 239.

12. Is light *always* refracted in passing from one medium to another?

13. How does a straight stick appear when partly immersed in water? Why?

14. Under what circumstances will the object and the image be on the same side of a convex lens?

15. Why will an iron gate that opens easily in winter often stick in summer?

16. What is meant by intermolecular spaces and how do they compare with molecular diameters?

17. How are centigrade and Fahrenheit thermometers graded?

18. Why are inland cities subject to greater extremes of temperature than seaside resorts?

19. Can rays of light cross one another without interfering with the effect of the rays?

20. The two sides of the greased paper photometer (§ 428, *b.*) are equally illuminated by a candle flame on one side, distant 18 inches, and by a lamp flame on the other side, distant 6 feet. How does the illuminating power of the lamp compare with that of the candle?

21. Are all the luminous rays of the same color?

22. Which is the more bulky, a pound of ice or a pound of water?

23. How can you make water boil at a lower temperature than 212° F.?

24. What is an anode? A node?

25. Does the vaporization of water change the size of the molecules or the distances between them?

26. How do you change centigrade into Fahrenheit readings?

27. What piece or pieces of physical apparatus *have you made* since you began studying this book?

28. What is meant by inertia?

29. How far will a freely falling body move in 10 seconds?

30. Which is the more general term, *fluid* or *liquid?*

31. Give a general law of machines.

32. How can energy be destroyed.

33. Define *force* and *energy.*

34. State Archimedes' principle.

35. Define specific gravity.

36. Explain gaseous tension.

37. Describe and explain the experiment with the Magdeburg hemispheres.

38. What is a dynamo?

39. Explain the action of intermittent springs.

40. Give Ohm's law.

41. What is the difference between noise and music?

42. Why does not Hudson Bay freeze solid to the bottom?

43. What is an ampere?

44. Explain interference of sound.

45. What is meant by *E. M. F.*?

46. What is meant by the "mechanical equivalent of heat"?

47. How should the cells of a voltaic battery be joined to give the best effect?

48. On what optical fact does the success of a sharpshooter (Fig. 240) depend?

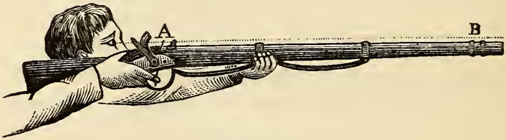

FIG. 240.

49. Do you think that you know all about Natural Philosophy?

APPENDIX

APPENDIX A.

Mathematical Formulas.

$\pi=3.14159$.
D=diameter.
R=radius.
Circumference of circle $=\pi D$.
Area of a circle $=\pi R^2$.
Surface of a sphere $=4\pi R^2=\pi D^2$.
Volume of a sphere $\frac{4}{3}\pi R^3=\frac{1}{6}\pi D^3$.

APPENDIX B.

International or Metric Measures.—This system bids fair to come into general use in this country. For this reason, as well as for its greater convenience, an acquaintance with it is now desirable and may soon be necessary. It has been already legalized by act of Congress. The meter is defined as the *forty-millionth of the earth's meridian* which passes through Paris. It is *equal to 39.37 inches.* Like the Arabic system of notation and the table of U. S. Money, its divisions and multiples vary in a tenfold ratio.

Metric Measures of Length.—Ratio$=10$.

DIVISIONS.	*Millimeter* (*mm.*)=	.001	*m.*=	0.03937 in.
	Centimeter (*cm.*) =	.01	*m.*=	0.3937 "
	Decimeter (*dm.*) =	.1	*m.*=	3.937 "
UNIT.	*Meter* (*m.*) =	1.	*m.*=	39.37 "
MULTIPLES.	Dekameter (*Dm.*)=	10.	*m.*=	393.7 "
	Hectometer (*Hm.*)=	100.	*m.*=	328 ft. 1 in.
	Kilometer (*Km.*) =	1000.	*m.*=	0.62137 mi.
	Myriameter (*Mm.*)=	10000.	*m.*=	6.2137 "

Note.—The table may be read: 10 millimeters make one centimeter; 10 centimeters make one decimeter, *etc.* (Fig. 241.) The denominations most used in practice are printed in italics. The system of nomenclature is very simple. The Latin prefixes, *milli-*, *centi-* and *deci-*, signifying respectively $\frac{1}{1000}$, $\frac{1}{100}$, and $\frac{1}{10}$, and already familiar in the mill, cent and dime of U. S. Money, are used for the divisions, while the Greek prefixes *deka-*, *hecko-*, *kilo-* and *myria-*, signifying respectively 10, 100, 1000 and 10000, are used for the multiples of the unit. Each name is accented on the first syllable. It may be noticed that the meter corresponds somewhat closely to the yard, which it will replace. Kilometers will be used instead of miles.

1 inch=	25.4000 *mm.*	=0.0254 *m.*	or about	$2\frac{1}{2}$ cm.
1 foot =	30.4800 *cm.*	=0.3048 *m.*	"	30 "
1 yard=	0.9144 *m.*		"	$\frac{10}{11}$ of a meter.
1 mile=	1609.0000 *m.*	=1.6090 *Km.*	"	$1\frac{6}{10}$ Km.

FIG. 241.

Metric Measures of Surface.—Ratio$=10^2=100$.

DIVISIONS.	Square millimeter (*sq. mm.*)	=0.000001	*sq. m.*
	Square centimeter (*sq. cm.*)	=0.0001	"
	Square decimeter (*sq. dm.*)	=0.01	"
UNIT.	Square meter (*sq. m.*)	=1.	"

etc., etc.

Note.—The table may be read: 100 *sq. mm.*=1 *sq. cm.*; 100 *sq. cm.*= 1 *sq. dm.*, *etc.* The reason for the change of ratio from 10 to 100 may be clearly shown by representing 1 *sq. dm.*, and dividing it into *sq. cm.* by lines, which shall divide each side of the *sq. dm.* into 10 equal parts or centimeters.

Metric Measures of Volume.—Ratio $=10^3=1000$.

DIVISIONS.	Cubic millimeter	(*cu. mm.*)	=0.000000001 *cu. m.*
	Cubic centimeter	(*cu. cm.*)	=0.000001 "
	Cubic decimeter	(*cu. dm.*)	=0.001 "
UNIT.	*Cubic meter*	(*cu. m.*)	=1.308 cu. yds.
	etc. etc.		

Metric Measures of Capacity.—Ratio=10.—For many purposes, such as the measurement of articles usually sold by dry and liquid measures, a smaller unit than the cubic meter is desirable. For such purposes the *cubic decimeter* has been selected as the standard, and when thus used *is called a liter* (pronounced *leeter*).

DIVISIONS.	Milliliter	(*ml.*)	= 1 *cu. cm.*	=0.061022 cu. in.
	Centiliter	(*cl.*)	= 10 "	=0.338 fld. oz.
	Deciliter	(*dl.*)	= 100 "	=0.845 gill.
UNIT.	*Liter*	(*l.*)	=1000 "	=1.0567 liquid qt.
MULTIPLES.	Dekaliter	(*Dl.*)	= 10 *cu. dm.*	=9.08 dry qt.
	Hektoliter	(*Hl.*)	=100 *cu. dm.*	=2 bu. 3.35 pk.
	Kiloliter	(*Kl.*)	= 1 *cu. m.*	=264.17 gal.

Fortunately, *there is but one liter.* This is intermediate, in value, between the dry and the liquid quarts which it will replace. The dekaliter does not differ very much from the peck and might be substituted for it without much confusion.

1 U. S. liquid quart	= 0.946 *l.*	or about	1 liter.
1 U S. dry "	= 1.101 *l.*	"	1 "
1 U. S. gallon	= 3.785 *l.*	"	$3\frac{8}{10}$ "
1 U. S. bushel	=35.240 *l.*	"	$\frac{4}{11}$ of a hektoliter.

Metric Measures of Weight.—Ratio=10.

DIVISIONS.	Milligram	(*mg.*) =	0.0154	grains	avoirdupois.
	Centigram	(*cg.*) =	0.1543	"	"
	Decigram	(*dg,*) =	1.5432	"	"
UNITS.	*Gram*	(*g.*) =	15.432	"	"
MULTIPLES.	Dekagram	(*Dg.*) =	0.3527	oz.	"
	Hektogram	(*Hg.*) =	3.5274	"	"
	Kilogram	(*Kg.*) =	2.2046	lbs.	"
	Myriagram	(*Mg.*) =	22.046	"	"

A gram is the weight of one cubic centimeter of pure water, at its temperature of greatest density (4° C. or 39.2° F.). A 5-cent nickel coin weighs five grams. Fortunately, *there is but one gram or one kilogram.*

1 avoirdupois ounce = 28.35 *g.* or a little less than 30 grams.
1 Troy or apothecaries ounce=31.10 *g.* or a little more than 30 grams.
1 avoirdupois pound 453.59 *g.* or about $\frac{5}{11}$ of a kilogram.

The best way for the pupil to become familiar with these weights and measures is to use them. He will quickly discover that very many computations with these units consist only of intelligent shiftings of the decimal point.

EXERCISES.

1. How much water, by weight, will a liter flask contain?

2. If sulphuric acid is 1.8 times as heavy as water, what weight of the acid will a liter flask contain?

3. If alcohol is 0.8 times as heavy as water, how much will 1250 *cu. cm.* of alcohol weigh?

4. What part of a liter of water is 250 *g.* of water?

5. What is the weight of a *cu. dm.* of water?

6. What is the weight of a *dl.* of water?

INDEX.

NUMBERS REFER TO PARAGRAPHS, UNLESS OTHERWISE INDICATED.

D.

E.

Q.

R.

S.

T.

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